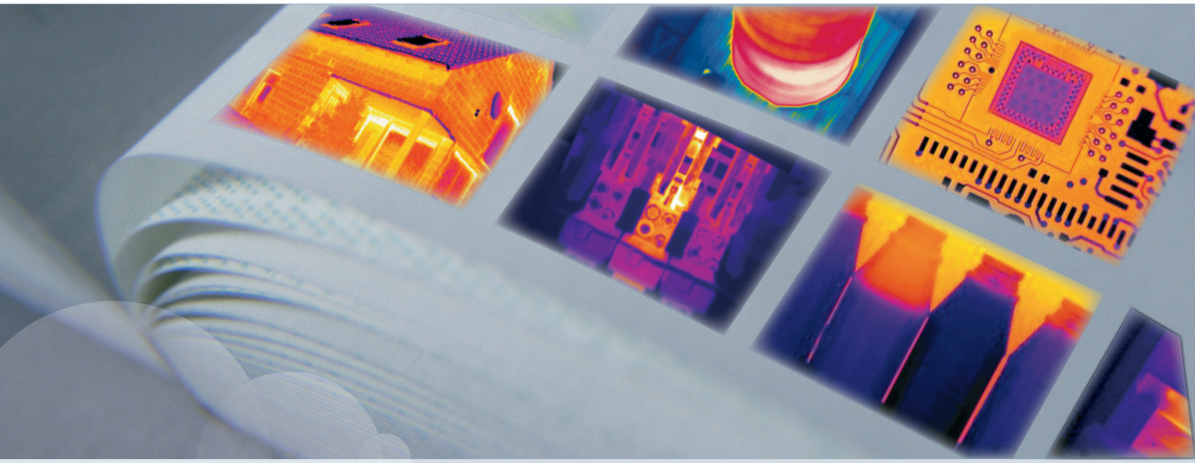
User's manual



ThermoVision™ SDK

Program version 2.6 SP2

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Notice to user 1

Customer help 2

ThermoVision™ SDK overview 3

FireWire™ configuration 4

Gigabit Ethernet interface configuration 5

Standard Ethernet interface configuration 6

User guide 7

Reference section 8

FLIR Public File image format 9

About FLIR Systems 10

Thermographic measurement techniques 11

History of infrared technology 12

Theory of thermography 13

The measurement formula 14

Emissivity tables 15

ThermoVision™ SDK

User's manual

Publ. No. T559014 Rev. a615 – ENGLISH (EN) – April 30, 2013

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Table of contents

1 Notice to user 1

2 Customer help 3

3 ThermoVision™ SDK overview 5
- 3.1 Main features 5
- 3.2 New features compared to ThermoVision™ SDK 2.6 SP1 5
- 3.3 True Temperature Analysis 5
- 3.4 Summary of API 6
- 3.5 System requirements 7
- 3.6 Recommended cameras 7
- 3.7 Necessary software & hardware 8
  - 3.7.1 FLIR Systems software 8
  - 3.7.2 Intel Gigabit Ethernet network adapter 8
- 3.8 Checklist 8
  - 3.8.1 Step-by-step instructions (only for cameras supporting FireWire™) 8

4 FireWire™ configuration 9
- 4.1 System parts: ThermaCAM™ S- and ThermoVision™ A-series – FireWire™ interface 9
- 4.2 Software limitations 10
- 4.3 PC recommendations 11
- 4.4 Installing the FireWire™ camera driver software 11
  - 4.4.1 General instructions 11
  - 4.4.2 Windows Vista and Windows 7 11
  - 4.4.3 Windows XP 12
- 4.5 Troubleshooting the FireWire™ installation 12

5 Gigabit Ethernet interface configuration 15
- 5.1 System parts: Gigabit Ethernet interface 15
- 5.2 Software limitations 17
- 5.3 PC recommendations 17
- 5.4 Installing driver software for the Gigabit Ethernet interface 18
  - 5.4.1 Windows® XP/Vista/7 18
- 5.5 Troubleshooting the Gigabit Ethernet interface installation 18

6 Standard Ethernet interface configuration 21
- 6.1 System parts: Standard Ethernet interface configuration 21
- 6.2 Software limitations 22
- 6.3 PC recommendations 22
- 6.4 Ethernet bandwidth requirements 22
- 6.5 Troubleshooting the standard Ethernet interface installation 23

7 User guide 25
- 7.1 About the camera control 25
- 7.2 About using multiple FireWire™ cameras 26
- 7.3 About using a FireWire™ camera with Windows® XP SP-2 26
- 7.4 Using the camera control 26
  - 7.4.1 Connecting 26
  - 7.4.2 Disconnecting 28
  - 7.4.3 Image types 28
  - 7.4.4 Camera action commands 28

7.4.5 Acquiring look-up tables ... 29
7.4.6 Setting and getting camera properties ... 29
7.4.7 Acquiring images ... 33
7.4.8 How to trigger a recording from outside ... 33
7.4.8.1 External trig using FireWire™ ... 34
7.4.8.2 External trig using the serial port ... 34
7.4.8.3 External trig using the printer port ... 34
7.4.9 Using the camera control with recorded images ... 34
7.4.10 Snapshot image acquisition uing TCP/IP ... 35
7.4.11 Image acquisition scenarios ... 35
7.4.11.1 Live image scenario (all camera types) ... 35
7.4.11.2 Live image scenario (absolute temperature image acquisition) ... 35
7.4.11.3 Snapshot scenario – long time intervals between image acquisitions ... 36
7.4.11.4 Distributed snapshot scenario (A-series Ethernet cameras) ... 36
7.4.12 Using the camera control with recorded images ... 37
7.4.13 Pushing images into the camera control ... 37
7.4.14 Talking directly to the camera ... 37
7.4.15 Using emissivity correction maps ... 37
7.4.16 Back calculation of emissivity factor ... 38
7.4.17 Translating signal value to temperature ... 38
7.4.18 Events ... 38
7.4.19 Public image format ... 38
7.5 Graphical user interface ... 39
7.5.1 ThermoVision™ A-series Camera Control ... 39
7.5.2 ThermaCAM™ S-series Camera Control ... 41
7.5.3 Indigo standard Ethernet™ interface ... 42
7.5.4 Indigo Merlin Camera Control ... 44
7.5.5 Indigo Omega Camera Control ... 45
7.5.6 Indigo Phoenix Camera Control ... 47
7.6 Redistribution ... 48
7.6.1 Camera Control Runtime Component ... 48
7.6.2 Bonjour Core Services 1.0.4 ... 48
7.6.3 FLIR Device Drivers ... 48
7.6.4 Ethernet Bus Drivers ... 48

8 Reference section ... 49
8.1 About the camera control ... 49
8.1.1 Description ... 49
8.1.2 File names ... 49
8.1.3 Interfaces ... 49
8.1.4 Camera control properties, methods and events ... 49
8.1.5 Data types ... 49
8.2 Properties ... 50
8.2.1 Version Property ... 50
8.3 Methods ... 50
8.3.1 AboutBox Method ... 50
8.3.2 Connect Method ... 50
8.3.3 Disconnect Method ... 52
8.3.4 DoCameraAction Method ... 52
8.3.5 EmissCalc Method ... 53
8.3.6 GetAbsLUT Method ... 54
8.3.7 GetObjLUT Method ... 54

8.3.8 GetCameraProperty Method ... 54
8.3.9 GetError Method ... 62
8.3.10 GetImage Method ... 63
8.3.11 GetImages Method ... 64
8.3.12 GetLUT Method ... 64
8.3.13 MLGetImages Method ... 65
8.3.14 SetCameraProperty Method ... 65
8.3.15 SetImage Method ... 66
8.3.16 SetEmissMap Method ... 66
8.3.17 SetDistanceMap Method ... 67
8.3.18 SubmitCamCommand Method ... 67
8.3.19 ToTemperature Method ... 68
8.4 Events ... 68
8.4.1 CameraEvent Event ... 68
8.4.2 CamCmdReply Event ... 69
8.4.3 ResourceChanged Event ... 69

9 FLIR Public File image format ... 71
9.1 General information ... 71
9.2 Basic data ... 71
9.3 The whole header data structure (size 892 bytes) ... 71
9.4 The image data structure (120 bytes) ... 72
9.5 The camera data structure (360 bytes) ... 72
9.6 The object parameters data structure (104 bytes) ... 72
9.7 The date and time data structure (92 bytes) ... 73
9.8 The scaling data structure (88 bytes) ... 73

10 About FLIR Systems ... 75
10.1 More than just an infrared camera ... 76
10.2 Sharing our knowledge ... 77
10.3 Supporting our customers ... 77
10.4 A few images from our facilities ... 77

11 Thermographic measurement techniques ... 79
11.1 Introduction ... 79
11.2 Emissivity ... 79
11.2.1 Finding the emissivity of a sample ... 80
11.2.1.1 Step 1: Determining reflected apparent temperature ... 80
11.2.1.2 Step 2: Determining the emissivity ... 82
11.3 Reflected apparent temperature ... 83
11.4 Distance ... 83
11.5 Relative humidity ... 83
11.6 Other parameters ... 83

12 History of infrared technology ... 85

13 Theory of thermography ... 89
13.1 Introduction ... 89
13.2 The electromagnetic spectrum ... 89
13.3 Blackbody radiation ... 90
13.3.1 Planck’s law ... 91
13.3.2 Wien’s displacement law ... 92
13.3.3 Stefan-Boltzmann's law ... 94
13.3.4 Non-blackbody emitters ... 95

13.4 Infrared semi-transparent materials 97

14 The measurement formula 99

15 Emissivity tables 105
15.1 References 105
15.2 Important note about the emissivity tables 105
15.3 Tables 106

1 Notice to user

Typographical conventions

This manual uses the following typographical conventions:

- **Semibold** is used for menu names, menu commands and labels, and buttons in dialog boxes.
- *Italic* is used for important information.
- `Monospace` is used for code samples.
- UPPER CASE is used for names on keys and buttons.

User-to-user forums

Exchange ideas, problems, and infrared solutions with fellow thermographers around the world in our user-to-user forums. To go to the forums, visit:

http://www.infraredtraining.com/community/boards/

Additional license information

This software is sold under a single user license. This license permits the user to install and use the software on any compatible computer provided the software is used on only one computer at a time. One (1) back-up copy of the software may also be made for archive purposes.

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2 Customer help

General

For customer help, visit:

http://support.flir.com

Submitting a question

To submit a question to the customer help team, you must be a registered user. It only takes a few minutes to register online. If you only want to search the knowledgebase for existing questions and answers, you do not need to be a registered user.

When you want to submit a question, make sure that you have the following information to hand:

- The camera model
- The camera serial number
- The communication protocol, or method, between the camera and your PC (for example, HDMI, Ethernet, USB™, or FireWire™)
- Operating system on your PC
- Microsoft® Office version
- Full name, publication number, and revision number of the manual

Downloads

On the customer help site you can also download the following:

- Firmware updates for your infrared camera
- Program updates for your PC software
- User documentation
- Application stories
- Technical publications

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3 ThermoVision™ SDK overview

3.1 Main features

- Supports communication and broadcasting via FireWire™, Ethernet, and USB interfaces.
- Gives the user full control of the camera.
- Allows the user to set alarm conditions and measurement functions in the camera
- Allows the user to define I/O functionality (FLIR A series).
- Based on ActiveX technology.
- Supports acquisition of images through FireWire™, Ethernet, and USB interfaces.
- Reads from and writes to file in FLIR Systems' proprietary file format and writes to files in FLIR Systems' open floating point format (*.fpf).
- Converts 16-bit absolute pixels into temperature pixels and several intermediate types of pixels formats, for maximum user flexibility. Applies to all camera models with temperature measurement capabilities.
- Allows 16-bit temperature linear outputs from FLIR A series cameras.
- Includes method that allows using individual emissivity value correction on any single pixel or condensed measuring value – *e.g.* average, minimum *etc*.
- Supports conditional recording to file through FireWire™, Ethernet, and USB interfaces.

3.2 New features compared to ThermoVision™ SDK 2.6 SP1

- Support for GF320/GF309
- Support for FLIR A615 and FLIR SC6X5 (including windowing)
- Support for windowing in FLIR SC640

3.3 True Temperature Analysis

ThermoVision™ SDK is a set of methods and events to manage the communications with a FLIR Systems IR camera in digital mode.

It provides the functions needed to:

- Set up communications between your application and the FLIR Systems IR camera.
- Capture and gather images via FireWire™, Ethernet, and USB interfaces.
- Adjust the camera configuration parameters and focus as you view a live image.
- Control the camera calibration.
- Send any other camera command to the camera.
- Generate a true temperature image from a 16-bit image acquired from the FireWire™, Ethernet, and USB interfaces.

- Close the communications to the IR camera.

3.4 Summary of API

Method	Description
AboutBox Method	You can use the **AboutBox** method to bring up the About box of the camera Control
Connect Method	Connect with the camera using the specified device, communication interface and port.
Disconnect Method	Disconnect the camera and exit the digital transfer mode.
DoCameraAction Method	Perform a specific camera action as listed below.
EmissCalc Method	Calculates a new emissivity factor for a specified pixel.
GetAbsLUT Method	Obsolete.
GetObjLUT Method	Get a pixel translation table. The table translates absolute image pixels to object pixels.
GetCameraProperty Method	Get specific camera property.
GetError Method	Converts a status code or error code to a formatted error string.
GetImage Method	Get a row-oriented image from the camera.
GetImages Method	Get a sequence of images from the camera.
GetLUT Method	Get a temperature translation table. The table translates absolute image pixels to temperature.
MLGetImages	Get a sequence of images. Used by MatLab.
SetCameraProperty Method	Set specific camera property.
SetDistanceMap Method	Set a distance correction map.
SetEmissMap Method	Set an image emissivity correction map.
SetImage Method	Set an image with absolute image pixel data. The image should be row-oriented.
SubmitCamCommand Method	Submits a user command to the camera.
ToTemperature Method	Converts a given absolute pixel value to temperature in Kelvin.

3.5 System requirements

ThermoVision™ SDK requires:

- Windows® XP SP2 (32- or 64-bit)
- Windows® Vista (32- or 64-bit)
- Windows® 7 (32- or 64-bit)
- Ethernet, FireWire™, or USB interface
- DirectX 8.1 (or higher) installed on your computer
- An IDE (Integrated Developer's Environment) which understands ActiveX components, e.g. Visual Basic or Visual C++

3.6 Recommended cameras

- ThermoVision™ A20 V FireWire™
- ThermoVision™ A20 V Ethernet
- ThermoVision™ A20 M FireWire™
- ThermoVision™ A20 M Ethernet
- ThermoVision™ A40 V Composite
- ThermoVision™ A40 V Ethernet
- ThermoVision™ A40 V FireWire™
- ThermoVision™ A40 M Ethernet
- ThermoVision™ A40 M FireWire™
- Omega, Merlin, and Phoenix cameras
- ThermaCAM™ S60/S65
- ThermaCAM™ S40/S45
- ThermaCAM™ SC640
- CPA 8200
- CPA 8000
- FLIR SC4000/SC6000
- FLIR A3X0
- FLIR A3X5 and SC3X5
- FLIR A615
- FLIR SC6X5
- FLIR GF320/GF309
- FLIR T series
- FLIR Exx series

If in doubt, please contact your local FLIR Systems distributor. Contact information can be found at *http://www.flirthermography.com*

3.7 Necessary software & hardware

3.7.1 FLIR Systems software

- ThermoVision™ SDK (P/N T197038)

Purchase information can be found at *http://www.flirthermography.com*

3.7.2 Intel Gigabit Ethernet network adapter

To achieve optimum speed image transfer using Indigo cameras, FLIR A3xx cameras, an Intel Pro / 1000 network adapter based on the Intel 82540, 82541 or 82546 chip is recommended.

3.8 Checklist

3.8.1 Step-by-step instructions (only for cameras supporting FireWire™)

The following test sequence can be carried out in order to make sure that the camera FireWire™ connection is working:

Step	Action
1	Install FSCAP from the ThermoVision™ A20 utility CD
2	Start the camera and connnect the camera FireWire™ cable to the PC
3	Start the FSCAP application by pointing to Start → Programs → FSCAP
4	Make sure that **FLIR ThermaCAM™** is selected under **Devices** and that **Preview** is selected under **Options**
5	You should now see a live image. Press ENTER to view the camera menu system. Use the arrow keys to navigate through the menu system. Press ESC to quit menu mode.
6	Try some other stream formats by selecting **Options** → **Video Capture Pin**. Select the **UYUV** option and 30 Hz frame rate. Now change the camera palette to a color palette.
7	Quit the FSCAP application.

4 FireWire™ configuration

4.1 System parts: ThermaCAM™ S- and ThermoVision™ A-series – FireWire™ interface

This configuration is used for the following camera models:

- ThermaCAM™ S60
- ThermaCAM™ S65
- ThermaCAM™ S40
- ThermaCAM™ S45
- ThermaCAM™ SC640
- CPA 8200
- CPA 8000
- ThermoVision™ A20 M FireWire™
- ThermoVision™ A40 M FireWire™

10430403;a2

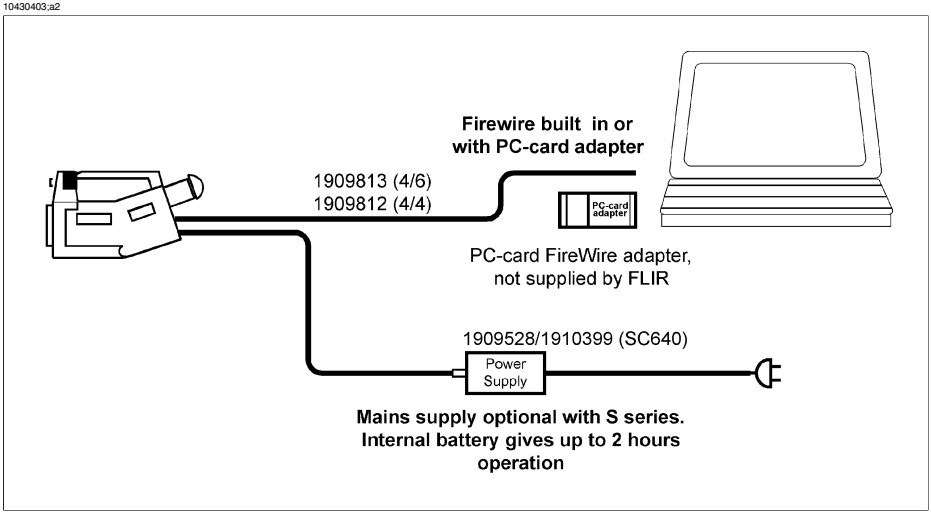

Figure 4.1 ThermaCAM™ S-series – FireWire™ interface & laptop computer

10430503;a2

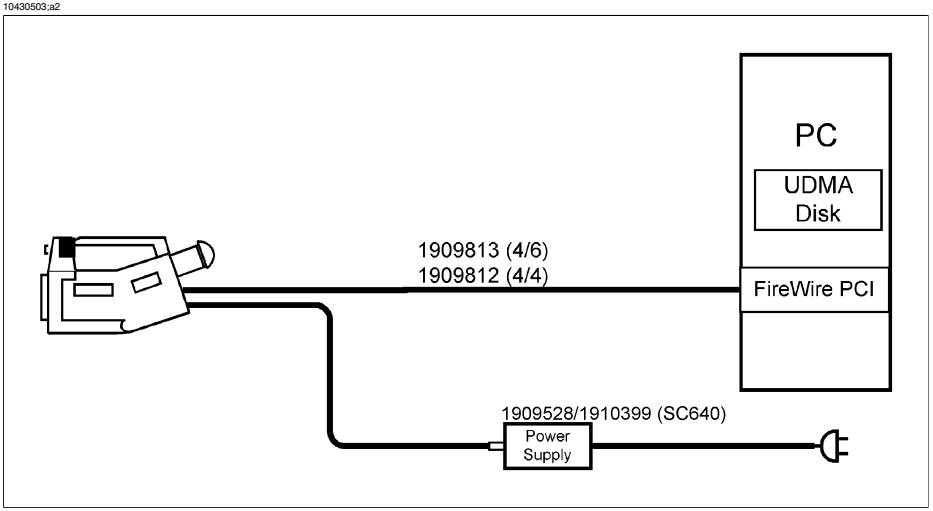

Figure 4.2 ThermaCAM™ S-series – FireWire™ interface & desktop computer

10430603;a1

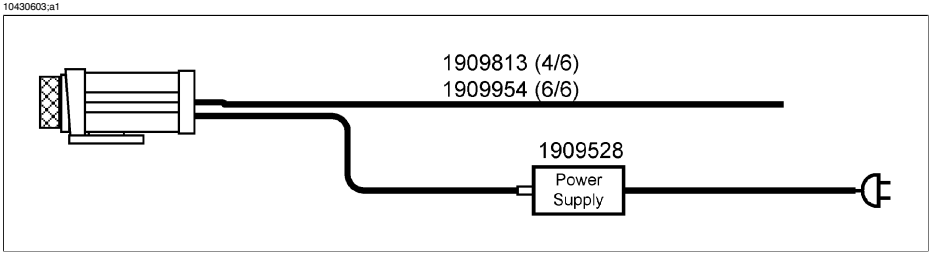

Figure 4.3 ThermoVision™ A-series – FireWire™ interface

Necessary parts:

- A FireWire™ cable, 6 pole/4 pole, max 4.5 m / 14.8 ft.
- A power supply (the camera battery can also be used)
- An optional FireWire™ hub, to be able to add a 6 pole/6 pole extension cable

4.2 Software limitations

The FireWire™ configuration works on Windows® XP,Windows® Vista, and Windows® 7 operating systems.

Full burst rate recording of the cameras is only possible when the target disk is formatted with a NT file system (NTFS) and is fast enough.

4.3 PC recommendations

To get a reasonably high performance you should have a Pentium desktop computer with a clock rate of 1 GHz or more.

If IDE Ultra DMA/100 is supported on your computer, then there is no need for striped SCSI disks. There are such disks that are so fast that you don't need to use striped volumes. We now recommend 7200 RPM 30 GBUltra DMA/100 disks (or better).

If you have a serial ATA disk (SATA) that is even better.

The FireWire™ adapter in the PC must conform to the 1394a-2000 specifications and must support bus speeds up to 400 Mb/s.

The amount of memory in the PC should be at least twice the Microsoft® recommendation.

Our recommendation is to set the color palette to 256 colors. TrueColor gives a lower frame rate, but better color fidelity.

4.4 Installing the FireWire™ camera driver software

4.4.1 General instructions

Step	Action
1	If needed, insert a FireWire™ Adapter into a free PCI bus slot on your desktop PC. The adapter must conform to the IEEE-1394a-2000 specification and be capable of supporting a serial bus speed of 400 Mb/s. Windows® should automatically detect the new hardware and ask for its drivers, which are supplied by the FireWire™ Adapter manufacturer
2	Disable any sensitive equipment (especially disks), that you may already have connected to your FireWire™ adapter.
3	Switch on the camera and check that the camera has the Digital Video Mode setting DCAM before you plug it into your computer. SC640 does not have this setting.
4	Connect the 1394 cable between the camera to the FireWire™ adapter of the PC when the camera is up and running.

4.4.2 Windows Vista and Windows 7

Step	Action
1	Please log in as Administrator during this installation. Windows® should detect the camera, after a while.

Step	Action
2	If Windows® displays a **New Hardware Found** Wizard for the device **FLIR ThemaCAM**, select **Locate and install** and **Don't search online**. Either insert the ThermaCAM™ Researcher CD-ROM or select **Don't have the disk** and **Browse my computer** to let Windows® find an appropriate driver on the CD or in your C:\Program Files\Flir Systems\FLIR Device Drivers directory.
3	Please allow Windows® to continue installing the software despite the complaints about the FLIR drivers not being digitally signed. If Windows® refuses to let you do this, please check that the Windows® Update Driver setting (Right-click on My Computer -> Properties -> Hardware tab) is not set to **Never**.
4	Some cameras will also contain a FLIR 1394 Network Adapter device. You can install it in the same way, if you like. ThermaCAM™ Researcher does not use it.

4.4.3 Windows XP

Step	Action
1	Log in as Administrator. Windows® should detect the camera after a while.
2	If Windows® displays a **New Hardware Found Wizard** for the device FLIR ThemaCAM, either let Windows® search for the best available driver or select **Install from a specific location (Advanced)** to let Windows® find an appropriate driver in your C:\Program Files\Flir Systems\FLIR Device Drivers directory.
3	Allow Windows® to continue installing the software despite the complaints about the FLIR drivers not being digitally signed. If Windows® refuses to let you do this, please check that the Driver Signing setting (Right-click on **My Computer** → **My Computer** → **Properties** → **Hardware** tab) is not set to **Block.**

There are cameras capable of supporting other devices, such as the FLIR 1394 Network Adapter and the FLIR USB Adapter. These devices belong to the ThermaCAM™ Connect 3.0 or ThermaCAM™ QuickReport product, which has drivers for them.

4.5 Troubleshooting the FireWire™ installation

To work properly, the FireWire™ configuration needs:

- Microsoft® Windows® XP, Windows® Vista, or Windows® 7
- Direct X 8.1 (or higher)
- A correct **Type of camera** and **Type of connection** setting in the **Select Camera** dialog.
- A 6 (or 4) to 4 FireWire™ cable for ThermaCAM™ S-series
- A 6 (or 4) to 4 FireWire™ cable for ThermaCAM™ SC640-series
- A 6 (or 4) to 6 FireWire™ cable for ThermoVision™ A-series
- A IEEE-1394a-2000 FireWire™ adapter
- A successful installation of the FireWire™ Adapter driver

- A camera equipped for FireWire™ digital output with its digital video mode set to DCAM
- The Driver Signing setting of the Windows® Device Manager should not block unsigned files
- The TCP/IP protocol Automatic Metric setting should not be set
- A successful installation of the FLIR ThermaCAM™ camera driver for each camera used
- A 1GHz (or faster) PC or laptop equipped with a IEEE-1394a-2000 interface capable of serial bus speed of 400 Mb/s.
- Recent updates from Microsoft® and the computer manufacturer
- With Windows® XP Service Pack 2, S series cameras must have filekit 2.2.5 (or higher) and A series cameras must have filekit 1.2.12 (or higher). The FLIR ThermaCAM™ driver must have version 5.20.2600.923 (or higher).
- Administrator rights (or a change in the Local Security Policy) for the users that plug in/out the camera on Windows® XP
- Proper settings if you have a firewall in your computer.
- Acrobat Reader from http://www.adobe.com

Some laptop computers are not equipped with the correct FireWire™ interface. In such cases, a proper FireWire™ interface can be added using a CardBus interface adapter. A desktop PC needs a free PCI slot in order to install a FireWire™ interface card. The FireWire™ connector of your PC may have 4 or 6 pins.

The IEEE-1394a-2000 adapter must be capable of a serial bus speed of 400 Mb/s in order to achieve full real time recording speed (50/60Hz). Even when this is the case, limitations elsewhere in the computer may not allow full speed.

With some laptop chipsets there is a problem cause by too much latency in the C3 power state transition which cause buffer underruns. This can be cured by a change in the Windows® registry. For more information, see Publ. No. T559004, Installation Hints, on the CD-ROM.

Since FireWire™ is a fairly recent addition to the Windows® world, hardware and software weaknesses still plague the technology. We recommend that you visit the Microsoft® Windows® Update website (windowsupdate.microsoft.com) to refresh your software and Windows® drivers, and that you visit the corresponding site of your computer manufacturer to receive its latest updates.

Do not connect other FireWire™ equipment to your computer when you transfer IR images.

Please disable any sensitive equipment (especially disks) that you may already have connected to your FireWire™ adapter before you plug in the camera.

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5 Gigabit Ethernet interface configuration

5.1 System parts: Gigabit Ethernet interface

This configuration is used for the following camera models:

- FLIR A3X5/SC3X5
- FLIR A615
- FLIR SC645
- FLIR SC655

10570003;a3

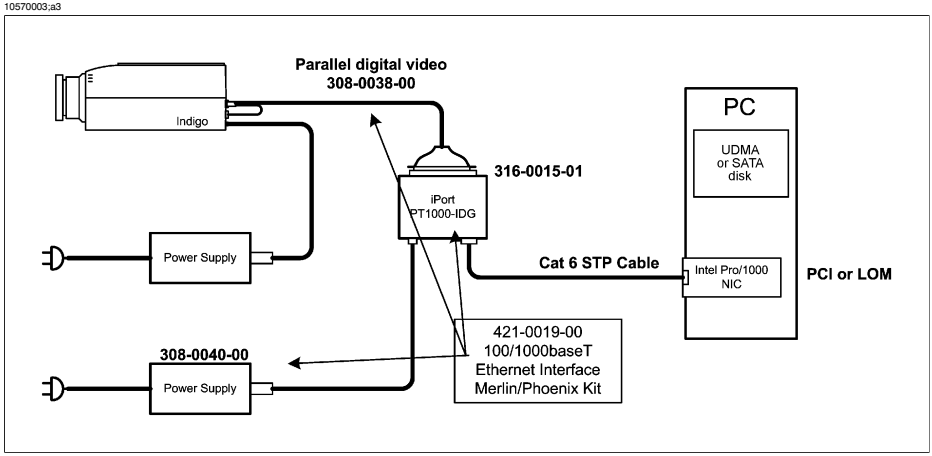

Figure 5.1 Indigo Merlin system parts. LOM = Lan on Motherboard.

10570103;a3

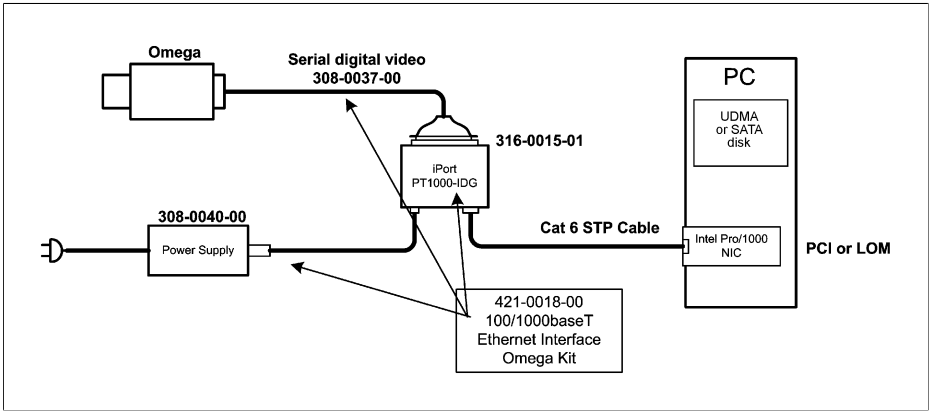

Figure 5.2 Indigo Omega system parts

10570203;a4

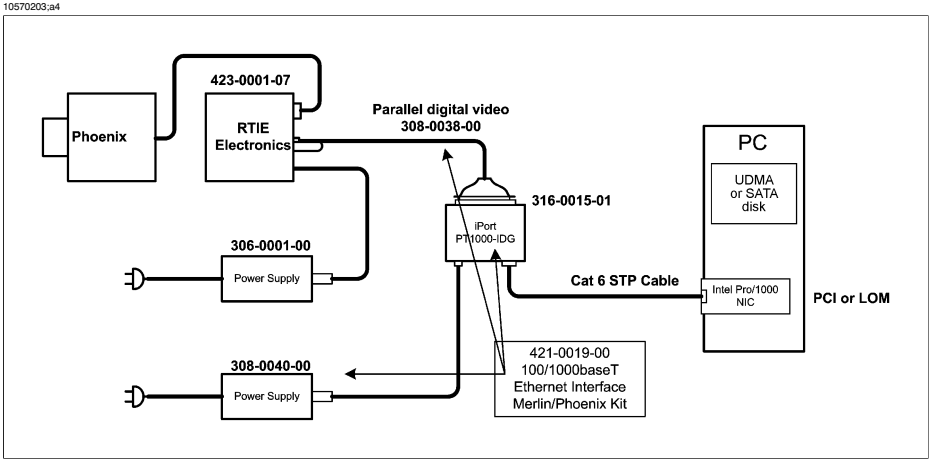

Figure 5.3 Indigo Phoenix system parts

10772003;a1

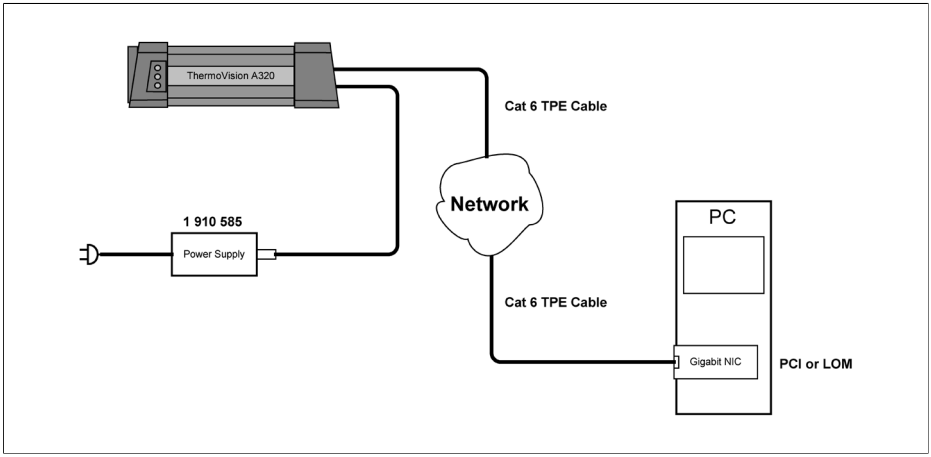

Figure 5.4 FLIR A3X5/SC3X5 and A615/SC6X5 system parts

Necessary parts:

- Intel PRO/1000 compatible Network Interface Card (NIC) in the PC
- A standard CAT6 STP Ethernet cable (up to 100 meters without intervening hardware).
- A desktop computer with a fast UDMA or SATA disk for high speed image storage

5.2 Software limitations

- The Gigabit Ethernet configuration works on Windows® XP, Windows® Vista, and Windows® 7 operating systems (all 32- and 64-bit).
- Full burst rate recording of the cameras is only possible when the target disk is formatted with a NT File System (NTFS).
- Pleora and eBus drivers are only supported on Windows® XP, Windows® Vista, and Windows® 7 operating systems (all 32- and 64-bit).

5.3 PC recommendations

Minimum requirements are:

- A Pentium 4 computer with a clock rate of 1.4 GHz or more.
- At least 512 MB RAM.
- Gigabit Ethernet network adapter (either PCI card or LAN on the motherboard).

To achieve burst recording it should have an 7200 rpm Ultra DMA/100 disk formatted with the NT file system (NTFS). Ultra DMA/100 requires Windows® XP, Windows® Vista (32-bit), and Windows® 7 operating systems.

If you have a serial ATA (SATA) disk, that is even better.

5.4 Installing driver software for the Gigabit Ethernet interface

5.4.1 Windows® XP/Vista/7

To take full advantage of the GigaBit interface you need the eBus optimal driver.

To copy the eBus driver suite onto your hard disk, run the installation program present on the CD. The Pleora eBus installation tool is available by running "C:\Program Files\Common Files\Pleora\EbDriverTool.exe".

Note that the eBus optimal driver is only compatible with the Intel PRO/1000 family of network adapters (either a PC network interface card, often referred to as a NIC, or a LAN on the motherboard, often referred to as a LOM). If you have some other kind of network adapter, use the universal driver instead.

The ordinary driver for your network adapter has almost certainly already been installed by Windows. You will have to update the previous installation with the Pleora driver.

You need to log in as administrator (or as a user with administrator rights) to do this.

Please follow these steps to replace your Gigabit network interface driver with the Pleora device driver:

1 First make sure that your computer has been fully updated by **Windows® Update**.
2 Run the Pleora installation tool. The Pleora eBus installation tool is available by running "C:\Program Files\Common Files\Pleora\EbDriverTool.exe".
3 Find your Gigabit Ethernet Adapter and select **Action**.
4 Select the optimal eBus Driver, if you have Intel PRO/1000 adapter, or the universal if you have another adapter. Click **Install**.
5 You may also have to update the new driver.
6 Press Exit and allow the computer to reboot.

You will have to let your computer's Firewall allow your application to access the network to be able to connect to your camera.

If you do not use an Intel PRO/1000 network adapter or do not install the Pleora drivers, the software will still allow you to set an IP number to the interface and try to connect to the camera using the ordinary networking functions of Windows. This connection will not give full speed performance for most cameras. For more information about this, please see section 4.3.

5.5 Troubleshooting the Gigabit Ethernet interface installation

To work properly, the configuration needs:

- Windows® /XP/Vista/7 (32- and 64-bit)
- A functional Gigabit Network Interface Card (NIC). Please note that configurations with more than one Gigabit network interface and optimum driver have not been tested.
- A successful installation of the optimum eBus device driver.
- A Pentium 4 computer with a clock rate of 1.4 GHz (or faster). At least 512 MB RAM.
- Select **Ethernet** as **Type of connection** in the **Select Camera** dialog.
- NetBIOS enabled on the TCP/IP connection to the camera
- Reliable cables and electrical connections. Gigabit Network adapters require shielded CAT6 cables.
- A camera equipped and configured for digital output.
- Proper settings if you have a firewall in your computer.

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6 Standard Ethernet interface configuration

6.1 System parts: Standard Ethernet interface configuration

This configuration is used for the following camera models:

- FLIR A3X0

10574003;a1

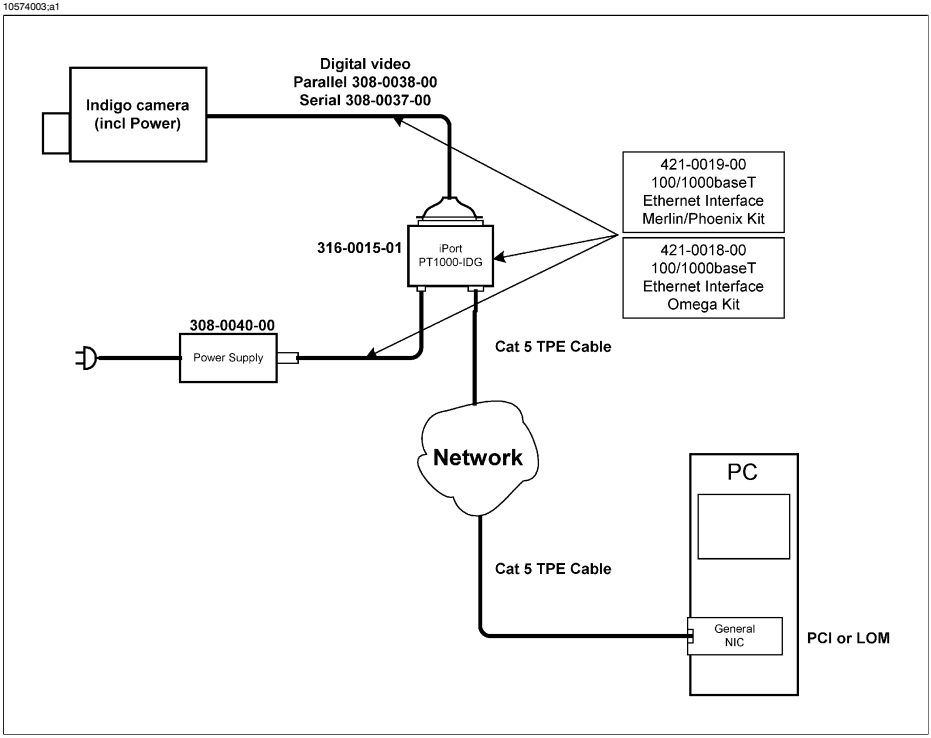

Figure 6.1 Indigo Merlin/Omega/Phoenix system parts. LOM = Lan on Motherboard.

10771903;a1

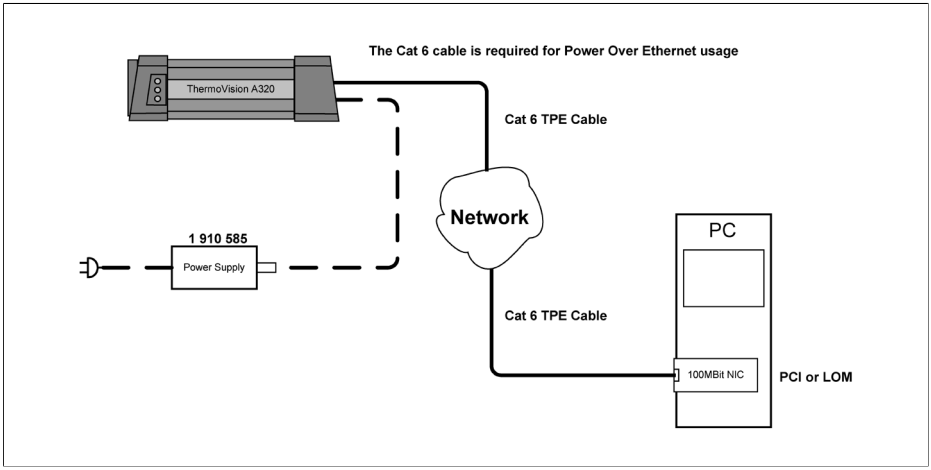

Figure 6.2 FLIR A3X0 system parts. LOM = Lan on Motherboard.

Necessary parts:

- Any network interface supporting at least Fast Ethernet (100 Mbit/s)
- A standard CAT5 Ethernet cable (up to 100 meters without intervening hardware)
- A desktop or laptop computer

6.2 Software limitations

The Ethernet configuration works on Windows® XP (32- and 64-bit), Windows® 7 (32- and 64-bit), and Windows® Vista (32- and 64-bit) operating systems.

Full burst rate recording of the cameras is not possible in this configuration.

6.3 PC recommendations

Minimum requirements are:

- A Pentium 4 computer with a clock rate of 1.4 GHz or more.
- At least 512 MB RAM.
- Any network interface supporting at least Fast Ethernet (100 Mbit/s)

6.4 Ethernet bandwidth requirements

It is important to understand that the cameras in this configuration will stream uncompressed digital video data on the network. This will consume a lot of bandwidth and can affect the normal network traffic causing congestions and slow response.

It is strongly recommended that you configure your network so that the digital video packet data does not affect any normal Ethernet traffic. Small local area networks designated for video streaming is recommended. These networks can either be Fast Ethernet or Gigabit Ethernet networks depending on the camera model (see figure below).

Figure 6.3 Network type recommendations

Camera model	Bandwidth requirement	Network recommendation
Merlin (60 Hz)	~100 Mbit/s	Use Gigabit Ethernet
Omega (30 Hz)	~12 Mbit/s	Use Fast Ethernet
Phoenix (60 Hz) Resolution 320 x 256	~100 Mbit/s	Use Gigabit Ethernet
Phoenix (60 Hz) Resolution 640 x 512	~400 Mbit/s	Use Gigabit Ethernet

6.5 *Troubleshooting the standard Ethernet interface installation*

To work properly, the configuration needs:

- Windows® XP/Vista/7 (32- and 64-bit)
- Any network interface supporting at least Fast Ethernet (100 Mbit/s)
- A Pentium 4 computer with a clock rate of 1.4 GHz or more. At least 512 MB RAM.
- Select **Ethernet** as **Type of connection** in the **Select camera** dialog box
- NetBIOS enabled on the TCP/IP connection to the camera
- Proper settings if you have a firewall in your computer
- Reliable cables and electrical connections
- A camera equipped and configured for digital output
- An IP number assigned to the interface
- An IP number assigned to the camera

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7 User guide

7.1 About the camera control

The ActiveX Control Module contains one interface named **FLIR SDK 2.6 Camera Control**. The control object name exposed to applications is **CAMCTRL.LVCamCtrl.3**

The camera control communicates with FLIR camera models:

- ThermoVision™ A20/A40
- ThermaCAM™ S60/S65/S40/S45
- Omega UL3 (ThermoVision™ A10)
- Merlin Uncooled MicroBolometer
- Merlin NIR (InGaAs)
- Merlin QWIP
- Merlin MID (InSb)
- Phoenix with RTIE
- ThermaCAM™ SC640
- FLIR SC4000/SC6000
- FLIR A3X0
- FLIR A3X5 and SC3X5
- FLIR A615
- FLIR SC6X5
- FLIR GF320/GF309
- FLIR T series
- FLIR Exx series

You can use it to switch camera measurement range, control the camera image filtering, view camera status etc. You can also retrieve images and temperature tables.

This control has methods, properties and events by which you can interact with it. The methods and properties allow you to give commands to the control and to retrieve information from it. The events can tell you that something important has happened, for instance that the user has pressed the disconnect button.

The distinction between methods and properties is quite subtle. Properties can be assigned one single value, which methods normally can not. Methods can take parameters, which properties normally can not. The intermediate case, a property with parameters, exists and is handled by this guide as a method because that is the way in which it is regarded by Visual Basic.

The purpose of this manual is to explain how to use the camera control.

7.2 About using multiple FireWire™ cameras

The FireWire™ protocol allows you to run and operate more than one camera using the FireWire™ bus in your computer. However, in order to avoid problems when changing frame rate, all cameras connected to the FireWire™ bus need to support the following camera software:

Camera model:	basedisk version:	which contains:
ThermaCAM™ S40/S60	2.0.4 (June 27th, 2003)	appl 2.4.4 edit 1
ThermoVision™ A20/A40	1.0.3 (April 29th, 2003)	appl 1.0.2 edit 2

7.3 About using a FireWire™ camera with Windows® XP SP-2

In order to work properly together with a PC with Windows® XP Service Pack 2, the camera needs to support at least the following camera software:

Camera model:	basedisk version:	which contains:
ThermaCAM™ S40/S60	2.3.2	appl 2.4.12 edit 3
ThermoVision™ A20/A40	1.3.1 (Dec 7th, 2004)	appl 1.0.14 edit 2

7.4 Using the camera control

7.4.1 Connecting

The very first thing to do is to connect to a camera. There is not much you can do before you are connected. There are a number of parameters to specify when connecting. First of all the camera type:

4	ThermaCAM™ S40/S60 (device type 3)
5	ThermoVision™ A20/A40 (device type 3, 4 and 5)
6	Coreby Indigo Merlin Series (device type 8)
7	Coreby Indigo Phoenix with RTIE backend electronics (device type 8)
8	Coreby Indigo Omega or ThermoVision™ A10 (device type 8)
9	FLIR SC4000/SC6000 (device type 8)
10	ThermaCAM™ SC640 (device type 3)
11	FLIR A3X0 (device type 6)
12	FLIR A3X5/SC3X5 (device type 8)
13	FLIR GF320/GF309 (device type 6 or 9)

14	FLIR T series (device type 6 or 9)
15	FLIR A615/SC6X5 (device type 8 or 9)
16	FLIR Exx series (device type 9)

Most likely you want to establish a control connection with the camera. The second parameter selects the communications port. Set this parameter to zero.

The third parameter is the *device type* used for image transfer from the camera to the PC. File device can be used for all camera types, which means that a replaceable test image is used as the image source.

2	File device
3	FireWire™ (16 bit image pixels)
4	Ethernet (8 bit image pixels)
5	FireWire™ (8 bit image pixels)
6	Ethernet (16 bit image pixels)
8	iPort/GEV frame grabber (using Ethernet)
9	USB

The fourth parameter selects the camera control communications *interface*. The *interface* parameter takes the following values:

0	No connection attempted. (Valid option for all camera types)
2	TCP/IP (Valid option for camera type 4 and 5 together with device type 4) (Also valid option for camera type 11, 12, and 13)
3	FireWire™ (Valid option for camera type 4 and 5 together with device type 3 and 5)
4	iPort/GEV (Valid option for camera type 6-9, 12, and 15 together with device type 8)
5	AXIS 2401 Video Server (Valid option for camera types 5 and 6)
6	USB Video

The *server* parameter is used for:

- Camera network IP address if the control communications interface is TCP/IP
- Video server IP address if the control communications interface is AXIS 2401
- Camera network IP address if the image source device is Ethernet.
- Preferred camera (using serial number) if more than one camera is connected to the FireWire™ bus

If the image source device is Ethernet, do NOT specify the RTP multicast address. The camera network IP address can be found in the camera GUI (Graphical User Interface). If device type is FireWire™ and you have more than one camera connected on the FireWire™ bus you can specify which camera you want to connect to by setting this parameter to the camera serial number.

You should wait for the Camera Connected event before acquiring any images or setting/getting other properties.

7.4.2 Disconnecting

Disconnects the camera and exits the digital transfer mode. You should always disconnect the camera before shutting down your application.

7.4.3 Image types

Image types must be specified when acquiring images. Below is list of valid image types.

0	Absolute image pixels (16-bit unsigned integers). Can only be used with 16-bit device types.
2	Object signal pixels (single precision float). Can only be used with 16-bit device types.
3	Absolute temperature pixels (single precision float).
4	Relative temperature pixels (8-bit unsigned integers). Can only be used with 8-bit device types.

Relative temperature pixels are related to the current lower and upper scale limit (property 8 and 9). The pixel value should be interpreted as an offset within the current scale limits. The scaling mode in the camera should be set to linear in order to translate this offset to a valid temperature.

A20V and A40V camera models only supports image type 4.

7.4.4 Camera action commands

Performs a specific camera action as listed below.

0	Start recording with current recording settings
1	Stop recording
2	Enable recording
3	Disable recording
4	Pause a started recording
5	Resume paused recording

6	Record a single image to disk (snapshot recording)
7	Show recording settings dialog box
8	Internal image correction (shutter maneuver)
9	External image correction
10	Auto adjust (without shutter maneuver)
11	Clear list of recorded files
12	Auto focus
13	Show camera information dialog box
14	Show device status dialog box
15	Reload calibration from camera
16	Simulate recording key trig (simulate F5 key trig)
19	Save camera settings file (requires TCP/IP connection and camera types 4 or 5)
20	Restore camera settings file (requires TCP/IP connection and camera types 4 or 5)

7.4.5 Acquiring look-up tables

Gets a pixel translation table. The table translates absolute image pixels to object pixels (**GetObjLUT**) or to temperature values (**GetLUT**). If successful, a memory block will be allocated for the translation table, and it is the responsibility of the caller to de-allocate the memory. The table size depends on the *tableType* parameter. The table returned is a one-dimensional array of *single precision float* (**GetObjLUT** and **GetLUT**).

0	Table size 256 (8-bit pixels). This is a valid option only for the **GetLUT** method.
1	Table size 65536 (16-bit pixels)
2	Table size 32768 (15-bit pixels)

A look-up table is valid until you receive a **LUT updated** event. When this event is received you need to call one of these methods again to update your copy of the look-up table.

7.4.6 Setting and getting camera properties

When the camera connection is established you can set and get a number of useful properties. Some of these properties need some further explanation.

SetCameraProperty and **GetCameraProperty** will, on error, return a signed 16-bit error code. Typical error conditions are, for example, a non-supported property, or if you try to write to a property that is read-only or if the camera is disconnected.

The properties with ID 0 to 11 are persistent properties. The current settings are stored in the registry and when a camera connection is established, these stored settings are sent to the camera.

Properties associated with recording settings (27-29 and 31-39) are also persistent properties.

The range of relative humidity is between 0 and 1.0. For example, a value of 0.65 means 65 % of relative humidity. Object distance is *always* in meter. Temperatures are *always* in Kelvin. The presentation unit properties only affect the way temperatures are displayed in the graphical user interface of the camera control.

Before using the measurement range property (12) you should find out the number of available measurement ranges. This is accomplished by getting the list of measurement ranges (property 46). If this property returns an array of three descriptive range strings, then 0, 1 and 2 are valid range options when setting the range property.

Recording trig port (property 32) determines which COM or LPT port to use when the recording trig source (property 31) is 1 (COM) or 2 (LPT).

If the recording file base name (property 37) is set to TEST, then the recording function will generate files with names like TEST0001.IMG or TEST0002.FFF. The maximum allowed number of characters in the base name is 10.

Property 47 can be used to disable and enable the automatic image correction function (NUC) in the camera. Please note that if this function is disabled for an extended period of time (more than 15 minutes), the temperature tables may be incorrect. Set this property to 0 to disable the automatic correction. Set this property to 1 to let the camera control software manage the automatic correction or set this property to 2 to let the camera manage the automatic correction.Property 61 (default initial mode) is only used with *camera type* 0. Set this property to 1 if you want the camera to always start with default video overlay settings. Set this property before connecting to the camera.

Property 65 (camera ID) can be used only with *camera type* 5, 11 and 12. This property sets or gets the camera ID, which by default is displayed on the camera video overlay.

The DirectX viewer property (70) is tightly associated with camera types 4 and 5 and the FireWire™ interface. This property can be used to enable or disable an Active Movie window displaying the image stream. You can also display a property page for the window where you can change the image palette. On Windows® XP platforms you'll need to install DirectX runtime version 9.0b in order to make the Active Movie window appear.

The image mode property (71) can only be used with *camera type* 5, 11 and 12. It is used to enable a hardware look-up table, which translates image pixels to absolute temperature pixels. If image mode is 1 (temperature resolution 0.1 K) or 2 (temperature resolution 0.01 K) the absolute image pixels should be interpreted as absolute temperature values. When image mode is 1, then the temperature range spans between 0 and 6553.5 K - e.g. a absolute image pixel with value 2735 should be interpreted as 273.5 K. In image 2 the valid range decreases to between 0 and 655.35 K and a absolute image pixel with value 35621 should be interpreted as 356.21 K.

The multicast property (72) is only relevant with *camera type* 5 and *device type* 4. If set, then a multicast session is attempted, otherwise a unicast connection (default) is attempted. Set this property before connecting to the camera. Multicast sessions reduce the load on the camera compared to unicast sessions, if more than one client is listening to the camera image transmission. However, please note that multicast support is required in all routers between the camera server and the camera control client.

The frame rate list property (75) returns a list of available frame rates. Use property 43 to modify the frame rate.

Properties 76 to 78 are used when you are connected as a file device and the current image source is a sequence file. Use property 76 to find out how many images there are in the sequence file. Use property 77 in order to jump to a specific image in the sequence. If property 78 is set to 1 then the GetImage method will wrap around to the first image after reading the last image in the sequence.

Property 79 is an option only valid for ThermoVision™ A20 cameras. If set, then images recorded on disk will consume less disk space (39 kB instead of 152 kB).

Property 82 enables or disables the emissivity correction function. Before enabling this function, you should use the SetEmissMap method to define a specific emissivity correction factor for each image pixel. After the correction function has been enabled, each temperature image will be corrected using the correction map. Please observe that this function has effect only when requesting an absolute temperature image.

Properties 83 and 84 control the ownership of scaling and object parameters. These properties should be set before connecting to the camera. If set, then the camera control will use saved registry settings for scaling and and object parameters and also try to transfer these settings to the connected camera. If not set, the camera control will (if possible) use the scaling and object parameters from the image source (camera or file).

Property 85 can be used to suppress popup dialog boxes. Set this property to 1 for silent mode (no popups).

Property 86 is a read-only property to find out if the camera can perform auto-focus operations. If this property is 0, then the camera has no auto-focus capability.

Property 87 is used for activating and deactivating resource subscriptions. First set a resource path using property 63. Add a new subscription by setting the property 87 to 1. Remove the subscription by setting the property to 0. This property is only valid for camera type 5, 11 and 12 together with TCP/IP or iPort PT1000 as communication interface. When the resource value changes, a ResourceChanged event will be fired from the camera control.

Property 88 is the image time stamp excluding milliseconds (read only). The property returns a value of the type DATE that is a 64-bit, floating-point fractional number of days since December 30, 1899. If the image source is file device, this property will return the current image file time stamp. If the image source is any other device, this property will return the time stamp of the last image acquisition.

Property 89 is the image time millisecond part (read only). If the image source is file device, this property will return the millisecond part of the current image file time stamp. If the image source is any other device, this property will return the millisecond part of the last image acquisition.

Property 90 is the current image trig count (read only). If the image source is file device, this property will return the trig count of the current image file, otherwise it will return the current trig count. The current trig source is determined by setting property 31.

Property 91 is the file format that will be used for snapshot recordings when the image source is file device and there is a TCP/IP control connection established with the camera. Set this property to a desired value before performing a snapshot recording. This property is only used with camera type 5, 11 and 12 using a TCP/IP communications interface and file device as image source. The valid formats are:

0	JPEG and non-compressed IR data (56 kB)
1	JPEG and PNG-compressed IR data (19 kB)
2	JPEG without IR data (16 kB)
3	Only IR and pixel data not compressed (40 kB), FLIR proprietary format (.FFF or .IMG)
4	Only IR and pixel data PNG-compressed (4 kB), FLIR proprietary format (.FFF or .IMG)

Image files with format 0, 1 or 2 can be viewed in any JPEG compliant image browser.

Property 92 is the file naming method used for snapshot recordings when the image source is file device and there is a TCP/IP control connection established with the camera.

0	Standard file naming (default)
1	Use date and time for file naming

7.4.7 Acquiring images

Use the **GetImage** method to acquire a single image from the camera. If successful, a memory block will be allocated for the image pixels, and it is the responsibility of the caller to de-allocate the memory. The image size depends on selected *camera type*. Examine the return VARIANT in order to determine the image size. The image consists of pixels of a certain type (see below), which you specify in the call to acquire an image. The image returned is row-oriented and structured as a 2-dimensional array. If anything goes wrong, the return VARIANT will only contain a 16-bit error code.

SEE ALSO: For more information about error codes, see section 8.3.9 – GetError Method on page 62

To acquire a correct temperature image using an Ethernet 8-bit camera interface, you'll need to set the adjust method to either **Brightness** or **Contrast**/**Brigthness**. Currently, this setting must be made directly in the camera using the camera menu system. A correct temperature image cannot be produced if the adjust method is based on an image histogram.

Use the **GetImages** method to acquire more than one image at a time. Before calling this method you need to allocate memory for each image. Each memory chunk should have at least the image size of the current camera type. Use the image type and the properties for image width (66) and image height (67) in order to determine the correct image size in bytes. The **GetImages** method expects a one-dimensional array of 32-bit image pointers where each pointer points to a pre-allocated image.

7.4.8 How to trigger a recording from outside

The parallel interface has a trig input connector, which is the default trig source. In addition, a free COM port or a LPT port can be used as the external trig source. These are mainly intended for usage with the PC-Card™ interface.

The external trig increments a trig counter which is stored with each image. For COM or LPT trigs, the counter only counts one trig pulse per image.

The source for the external trig is selected from the **Recording Conditions** dialog box in the camera control panels.

7.4.8.1 External trig using FireWire™

In ThermoVision™ A20 and A40 cameras, you can mark image frames at the instant an alarm was triggered. By doing so certain trigger information is assigned to the image and the frame can be then identified in the FireWire™ data stream by the camera control. You can, for example, use this trigger information to make the camera control start or stop a recording.

7.4.8.2 External trig using the serial port

This trig source option uses the CTS input line on a free COM port. The COM port has an RS-232 electrical interface.

Trig input using COM port	
DSUB-25 Pin 5: Trig Input.	Transition Low (<-3 V) to High (>+3 V) =trig. Close pin 4 and 5 to trig.
DSUB-9 Pin 8: Trig Input.	Transition Low (<-3 V) to High (>+3 V) =trig. Close pin 7 and 8 to trig.

SEE ALSO: For a more detailed description of the electrical interface, read the RS-232 specification.

7.4.8.3 External trig using the printer port

The printer port (LPT) option is only available on Windows® 95/98/ME platforms. This trig source option uses a control signal on a free LPT port. The LPT port has a TTL electrical interface.

Trig input using LPT1 (or LPT2) DSUB 25 pin printer port.	
Pin 10: Trig Input.	Open circuit = high. (+2.4 V to + 5 V) Transition High -> low =trig.
Pin 22: Ground	Closing 10 - 22 = trig.

The LPT1 port is normally associated with the physical hexadecimal address 378 and the LPT2 port is associated with address 278. The camera control assumes that this is the case. Check your parallel port configuration in the **Control Panel → System** icon, to find out the physical address associated with the parallel port.

7.4.9 Using the camera control with recorded images

After recording an image sequence at high speed you probably want to process it. Connect using file device and no communications interface. Select the same camera type that was used for the recording. Use property 53 to set a new IR image source file (either a single snapshot image or a sequence file) and then use the method GetImage as usual. If the the IR source is a sequence file, then each call made to GetImage will deliver the next image in the sequence. Use property 76 to find out

how many images there are in the sequence file. Use property 77 in order to jump to a specific image in the sequence. If property 78 is set to 1 then the GetImage method will wrap around to the first image after reading the last image in the sequence.

If the IR source file is a single image then each call to GetImage will naturally produce the same image. If no source file has been set, then a test image will be returned.

7.4.10 Snapshot image acquisition uing TCP/IP

There is a way to record single images without using an image source device. Camera type 5 (ThermoVision™ A20/A40)and camera type 11 and 12 (FLIR A3X0, A3X5/SC3X5, A615/SC6X5) that have an Ethernet interface can be used in this way. Connect using File device as image source and TCP/IP or iPort PT1000 as control communications interface. Don't forget to specify correct camera type and camera network address. Use the property number 91 to set the desired camera file format. Formats 0 and 1 will produce a JPEG image file with graphic dump and IR data, format 2 produces a JPEG file with only a graphic dump, and format 3 and 4 will produce a FLIR proprietary image file. Please note that the format 2 image files are ordinary JPEG files and cannot be used by the camera control. File formats 0-2 can be viewed in any JPEG compliant image browser software.

7.4.11 Image acquisition scenarios

Below are a number of typical image acquisition scenarios. These scenarios will give you a hint on the preferred way to acquire and process images.

7.4.11.1 Live image scenario (all camera types)

Step	Action
1	Connect
2	Wait for the Connected event (connection to camera completed)
3	Set your working environment (object parameters and range)
4	Acquire a look-up table – Use GetLUT (1) method
5	Acquire absolute pixel image – Use GetImage (0)
6	Process and display your image using the look-up table Repeat step 5 and 6 as long as you like. Update your look-up table every time you get the event Table updated
7	Disconnect

7.4.11.2 Live image scenario (absolute temperature image acquisition)

Step	Action
1	Connect

Step	Action
2	Wait for the Connected event (connection to camera completed)
3	Set your working environment (object parameters and range)
4	Set image mode – SetCameraProperty (property ID 71)
5	Acquire absolute image – Use GetImage (0)
6	Process and display your image Repeat step 5 and 6 as long as you like.
7	Disconnect

7.4.11.3 Snapshot scenario – long time intervals between image acquisitions

Step	Action
1	Connect
2	Wait for the Connected event (connection to camera completed)
3	Set your working environment (object parameters and range)
4	Acquire absolute temperature image – Use GetImage(3)
5	Process and display your image Repeat step 4 and 5 as long as you like.
6	Disconnect

7.4.11.4 Distributed snapshot scenario (A-series Ethernet cameras)

Step	Action
1	Connect using file device and TCP/IP communications interface
2	Wait for the Connected event (connection to camera completed)
3	Set your working environment (object parameters and range)
4	Acquire absolute temperature image – Use DoCameraAction(6) followed by GetImage(3)
5	Process and display your image Repeat step 4 and 5 as long as you like.
6	Disconnect

7.4.12 Using the camera control with recorded images

After recording an image sequence at high speed you probably want to process it. Connect using file device and no communications interface. Select the same camera type that was used for the recording. Use property 53 to set a new IR image source file (either a single snapshot image or a sequence file) and then use the method GetImage as usual. If the the IR source is a sequence file, then each call made to GetImage will deliver the next image in the sequence. Use property 76 to find out how many images there are in the sequence file. Use property 77 in order to jump to a specific image in the sequence. If property 78 is set to 1 then the GetImage method will wrap around to the first image after reading the last image in the sequence.

If the IR source file is a single image then each call to GetImage will naturally produce the same image. If no source file has been set, then a test image will be returned.

7.4.13 Pushing images into the camera control

The method **SetImage** can be used if you want to force the camera control to use a absolute pixel image. The absolute pixel images are probably acquired using a third party digital frame grabber connected to the camera. In this case the camera control is probably only used to establish a control connection with the camera. That means using *device type* None (= 2) when connecting to the camera.

The image provided must be row-oriented and structured as a 2-dimensional array with absolute pixels in 16-bit integer format. The array dimensions can be of any size. Subsequent calls to **GetImage** will return this new image.

7.4.14 Talking directly to the camera

Submits a direct control command to the camera. The response from the camera is returned in the **CamCmdReply** event. Do not use the method **SubmitCamCommand** for camera types 4, 5, 11-16. For these *camera types* you should use camera properties 63 and 64. Each type of camera has a set of commands of which only a subset is exposed through the camera control. In order to use these direct methods you need to have a description of available commands for your specific camera.

The properties available for FLIR A3X0 are described in the document “Basic ICD FLIR IR Camera - PC”.

7.4.15 Using emissivity correction maps

The method **SetEmissMap** can be used for emissivity correction on temperature images. Use the method **SetEmissMap** to define an emissivity map, which should be equal to the size of the IR source image. Each correction factor in the emissivity map may be in the range from 0.01 to 1.00. Use property 82 to enable or disable the emissivity correction function. The emissivity correction function, when enabled, re-

calculates a temperature image (requested by the method GetImage(3)) according to the current emissivity correction map. When activated, this function will affect the performance of the image acquisition.

7.4.16 Back calculation of emissivity factor

The method **EmissCalc** calculates a new emissivity factor for a specified pixel. The image pixel position and a known temperature (in Kelvin) for this position are supplied as input parameters. The method will perform an internal image acquisition and do a back calculation using the pixel position and the known temperature value. The known temperature value should not be too close to the object ambient temperature. If successful, a new calculated emissivity factor (float) is returned.

7.4.17 Translating signal value to temperature

The method **ToTemperture** converts a single absolute pixel value to temperature in Kelvin. If the emissivity factor is 0, then the current emissivity is used. The return temperature floating-point value is in Kelvin. If a valid emissivity factor is specified (<= 1.0), the absolute pixel value is converted to temperature using this emissivity factor.

7.4.18 Events

Camera *state events* are sent for a number of reasons. An event occurs when a camera connection changes state. Events can also be thrown for camera state changes, which affect the image distribution (events 8 and 9).

SEE ALSO: For more information about event codes, see section 8.4.1 – CameraEvent Event on page 68

Camera *command events* occur when the camera control receives a response from a direct command issued by the **SubmitCamCommand** method.

Camera *resource changed events* occur when the camera control has an active resource subscription and the resource value changes. This event is only available for camera type 4 and 5.

7.4.19 Public image format

The xxxx.fpf files consist of a header followed by a 2-dimensional array of single precision IEEE floating-point values, each representing one point of the image. A C-style description of the header layout can be found in the header file fpfimg.h , available in FSWIN example directory. The image point values are stored starting from the top left corner, row by row. The camera control can only save FPF images with absolute temperature floating-point values. In the FSWIN sample you can find code that reads a FPF image and displays the content.

7.5 Graphical user interface

7.5.1 ThermoVision™ A-series Camera Control

The SDK allows you to connect A-series cameras either through a FireWire™ interface or through an Ethernet™ interface.

ThermoVision™ model	Interface
A20 M/V Ethernet™	None
A40 M/V Ethernet™	None
A20 M FireWire™	FireWire™
A40 M FireWire™	FireWire™
A20 V FireWire™	None
A40 V FireWire™	None
FLIR A3X0	Standard Ethernet™
▪ FLIR A3X5/SC3X5 ▪ FLIR A615 ▪ FLIR SC6X5	Gigabit Ethernet™

When more than one camera is detected, this dialog box is displayed.

10770203;a1

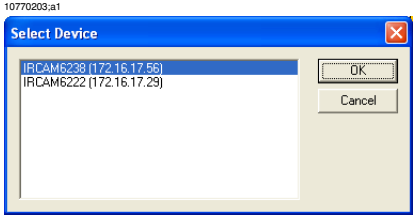

Figure 7.1 **Select device** dialog box

The Ethernet™ cameras will not be detected, unless they have been assigned an IP-number (like 172.16.17.56 above). This can be done automatically by a DHCP server or manually by a utility program which is distributed with the camera.

The control panel below is used for the ThermoVision™ A-series cameras.

10431203;a1

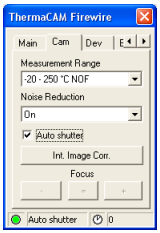

Figure 7.2 **ThermoVision™ A-series FireWire™** dialog box

If some button is disabled on your camera control, it is because your particular camera does not support that function.

The selected **Measurement Range** should cover the expected measurement temperatures. The range limits are blackbody temperatures, so if your measurement target has a shiny surface with a low emissivity, you will be able to make measurements above the range limits.

If you click the **Int. Image Correction** button on the **Camera Control** panel, the camera will respond by making a rather heavy clicking sound when the internal shutter is pulled and adjust its own temperature scale once to the current image. It is highly recommended to use the **Int. Image Correction** function now and then, since it improves the image quality. Select the **Auto shutter** option if you want an automatic internal image correction. This automated process can be disabled as it may affect the recording of images. When you switch it off, a warning will appear on the status field of the control. This warning will become red if you leave it switched off for a long time.

NOTE: There is a related function in the **Image** menu, on the standard toolbar and on the scaling toolbar. That function is called **Auto Adjust**. It will continuously adjust the scale to the image locally, within the PC.

If noise reduction is set to **On**, it will blur the image of moving objects.

The **Downsample** checkbox is only available for A20 cameras. This option affects how much disk space each image will occupy when stored on the hard disk. If enabled, disk space for each image will be significantly reduced. However, a performance penalty (in terms of apparent image quality, but not in measurement) is introduced when storing and reading image files.

10430703;a2

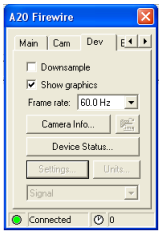

Figure 7.3 **ThermoVision™ A-series FireWire™** dialog box

Select the desired frame rate from the list box. The frame rate specifies how many images per second will be captured of the target in question.

NOTE: For cameras with a fixed frame rate, this selection will be unavailable.
NOTE: For some cameras, frame rates higher than 25/30 Hz may not be supported.
NOTE: For some computers, frame rates higher than 25/30 Hz may not work properly.

7.5.2 ThermaCAM™ S-series Camera Control

This control panel is used for ThermaCAM™ S60, ThermaCAM™ S40, ThermaCAM™ SC640, SC660, and similar camera models.

10419103;a1

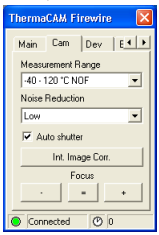

Figure 7.4 **ThermaCAM™ S-series FireWire™** dialog box

If some button is disabled on your camera control, it is because your particular camera does not support that function.

The selected **Measurement Range** should cover the expected measurement temperatures. The range limits are blackbody temperatures, so if your measurement target has a shiny surface with a low emissivity, you will be able to make measurements above the range limits.

If you click the **Int. Image Correction** button on the **Camera Control** panel, the camera will respond by making a rather heavy clicking sound when the internal shutter is pulled and adjust its own temperature scale once to the current image. It is highly recommended to use the **Int. Image Correction** function now and then, since it improves the image quality. Select the **Auto shutter** option if you want an automatic in-

ternal image correction. This automated process can be disabled as it may affect the recording of images. When you switch it off, a warning will appear on the status field of the control. This warning will become red if you leave it switched off for a long time.

NOTE: There is a related function in the **Image** menu, on the standard toolbar and on the scaling toolbar. That function is called **Auto Adjust**. It will continuously adjust the scale to the image locally, within the PC.

At the bottom of the **Cam** tab, there are three focus buttons: Near focus (–), auto focus (=) and far focus (+).

If noise reduction is set to **Low** or **High**, it will blur the image of moving objects.

The camera control will block the camera power down function to ensure proper operation during image recording. To prevent the camera from shutting down when disconnected, make sure that the power down timeout is disabled in the camera.

10566703;a1

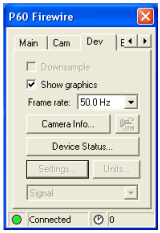

Figure 7.5 ThermaCAM™ S-series FireWire™ dialog box

Select the desired frame rate from the list box. The frame rate specifies how many images per second will be captured of the target in question.

For cameras with the windowing option, the highest frame rates will lead to a reduction of the image height.

NOTE: For cameras with a fixed frame rate, this selection will be unavailable.
NOTE: For some cameras, frame rates higher than 25/30 Hz may not be supported.
NOTE: For some computers, frame rates higher than 7 Hz may not work properly.
NOTE: Use the **Normalized connection** command on the ThermaCAM™ Researcher **Camera** menu if connection fails due to a too high frame rate.

7.5.3 Indigo standard Ethernet™ interface

This chapter applies to all Indigo camera models, when the optimum eBus driver is not used.

It is possible to use a standard network interface in order to acquire images from an iPort frame grabber device connected to the network. Please note that the standard network interface is scanned only if no frame grabber device can be detected over the optimum driver connection.

The iPort frame grabber device can be connected to a host PC either directly or through a network switch. If a device is detected on any of your standard Ethernet™ network interfaces, the following dialog box will be presented:

10573803;a2

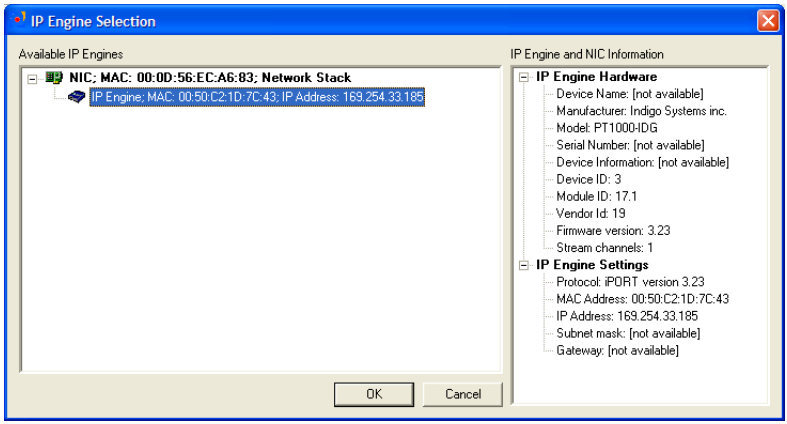

Figure 7.6 Network Device Finder dialog box

The device identification process can take quite a long time in Windows®. Until it has finished, you will get a **Device not present** message.

A list of detected devices will be presented. If the device has been given an IP address it will be displayed. If the IP address is not shown or if the IP address needs to be modified, then select any adapter entry in the adapter list directly below the device entry. Right-click the adapter entry and select **Set IP…** from the context menu. A dialog box will be presented:

When the IP address has been set, click OK in the **Network Device Finder** dialog box to proceed with the connection process.

SEE ALSO: For more information, see section 6 – Standard Ethernet interface configuration on page 21.

7.5.4 Indigo Merlin Camera Control

This control panel is used for Indigo Merlin cameras.

10569603;a1

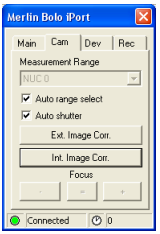

Figure 7.7 Merlin Bolometer iPort – camera control tab

If a button is disabled on your camera control, it is because your particular camera does not support that function.

The **Measurement Range** list contains a list of all available NUC tables in the camera. Each NUC table corresponds to a measurement temperature range. The camera is delivered with a set of pre-defined NUC tables, but user-defined NUC tables can be added to the camera. There is a small windows application on the CD designed for this purpose in the *Indigo MerlinUI* sub directory. The names of the NUC tables can be changed to more user-friendly names.

Select the **Auto range** option if you want the camera to select the best suitable measurement range (or NUC table).

If you click the **Int. Image Correction** button on the **Camera Control** panel, the camera will respond by making a clicking sound when the internal shutter is pulled and adjust its own temperature scale once to the current image. It is highly recommended to use the **Int. Image Correction** function now and then, since it improves the image quality.

Select the **Auto shutter** option if you want an automatic internal image correction. This automated process can be disabled as it may affect the recording of images. When you switch it off, a warning will appear in the status field of the control. This warning will turn red if you leave it switched off for a long time.

NOTE: There is a related function on the **Image** menu, on the standard toolbar and on the scaling toolbar. That function is called **Auto Adjust**. It will continuously adjust the scale to the image locally, on the PC.

If you try to study targets whose temperatures are close to or even outside the measurement range, it might happen that the image becomes noisy due to detector offset errors. That is when you should use the **External Image Correction** function. Aim the camera towards a surface with a flat temperature close to that of the target. Click the button. The image will now be subjected to an offset correction so that every part of

the image will get the same value as that in the middle. Aim the camera towards the target again. This correction will last until the next time you internally correct the camera image, or run **Ext. Image Correction** again.

10569703;a1

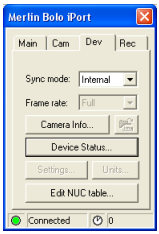

Figure 7.8 Merlin Bolometer iPort – device control tab

Select the desired **Sync mode** from the list box. An external sync signal can be applied in order to synchronize the camera with other external equipment.

Select the desired frame rate from the list box. The frame rate specifies how many images per second will be captured of the target in question. Full frame rate corresponds to either 50 (PAL) or 60 (NTSC) images per second depending on video mode.

Set user-friendly names on the camera NUC tables by using the **Edit NUC** table button. You can also add more items to the name list in case the camera contains more than the default number of NUC tables.

7.5.5 Indigo Omega Camera Control

This control panel is used for Indigo Omega cameras.

10569803;a1

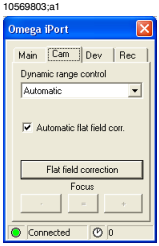

Figure 7.9 Omega iPort – camera control tab

If a button is disabled on your camera control, it is because your particular camera does not support that function.

The **Dynamic range control** contains a list of the available modes for range control. The camera has two modes, one for low-temperature scenes (below 150 °C) and one mode for high-temperature scenes (up to 500 °C). If the camera has the optional automatic dynamic range control feature, then an automatic mode is also available.

If you click the **Flat field correction** button on the control panel, the camera will respond by making a clicking sound when the internal shutter is pulled and adjust its own correction coefficients. It is highly recommended to use the **Flat field correction** function now and then, since it improves the image quality.

Select the **Auto flat field corr.** option if you want an automatic flat field correction. This automated process can be disabled as it may affect the recording of images. When you switch it off, a warning will appear on the status field of the control. This warning will become red if you leave it switched off for a long time.

NOTE: There is a related function in the **Image** menu, on the standard toolbar and on the scaling toolbar. That function is called **Auto Adjust**. It will continuously adjust the scale to the image locally, within the PC.

10569903;a1

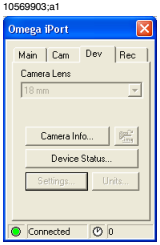

Figure 7.10 Omega iPort – device tab

If the Omega camera has been calibrated for more than one lens, then the **Camera Lens** list box will be enabled. Select the correct lens from the list after a lens switch to notify the camera of the change.

7.5.6 Indigo Phoenix Camera Control

This control panel is used for Indigo Phoenix cameras.

10573703;a2

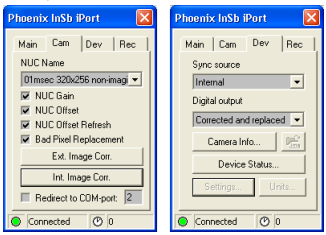

Figure 7.11 Phoenix iPort – camera control tabs

If a button is disabled on your camera control, it is because your particular camera does not support that function.

The **NUC Name** list contains a list of all available NUC tables. These tables include integration time, window size etc. The Phoenix camera system can internally store a number of these NUC tables. NUC tables can be added or edited using an application delivered with the camera.

The check boxes below allow you to enable or disable various processing of the digital video stream along the digital video path. Specifically, aspects of the active NUC table and the associated bad pixel map can be enabled or disabled independent of each other by using these check boxes. Typically, all of these check boxes would be enabled, but depending on the application, you can choose to bypass selected parts of the NUC and bad pixel replacement. Bypassing part of the NUC or bad pixel replacement in this way affects both the digital video output and the analog video output.

- **NUC Gain**: Check this option when you want the active NUC gain coefficients to be applied to the individual pixel digital values
- **NUC Offset**: Check this option when you want the active NUC offset coefficients to be applied to individual pixel digital values
- **NUC Offset Refresh**: You should check this option if you want the NUC offset refresh coefficients (if any exist) to be applied
- **Bad Pixel Replacement**: This option enables bad pixel replacement

If you click on the **Int. Image Correction** button on the Camera Control panel, the camera will respond by making a clicking sound when the internal shutter is closed and the camera adjusts its own offsets to the current image. It is highly recommended to use the **Int. Image Correction** function now and then (especially at power up), since it improves the image quality.

It is often desirable to use an external normalization source, as opposed to the internal shutter, since any non-uniformity in the camera lens is then also corrected. To do that, use the **Ext. Image Correction** button. Aim the camera towards a surface with a flat temperature close to that of the target. Click the button. The image will now be subjected to an offset correction so that every part of the image will get the same value as that in the middle. Aim the camera towards the target again. This correction will last until the next time you internally correct the camera image, or run **Ext. Image Correction** again.

The **Sync source** controls the synchronization of the FPA integration period in non-imaging mode. In imaging mode the sync signal is used to actively start the readout of valid video.

The **Digital ouput** control sets restrictions for the check boxes on the **Cam** tab:

- Uncorrected output (no corrections allowed)
- Corrected output (only NUC corrections allowed)
- Corrected and replaced output (all corrections allowed)

7.6 Redistribution

7.6.1 Camera Control Runtime Component

To install the FLIR SDK Camera Control together with your application, please use the supplied installer, which can be found on the CD. The file name of the installer is “ThermoVision™ SDK Runtime.msi”.

If the computer does not have Visual C++ installed, you probably need to install the Microsoft Visual C++ Redistributable Package (x86). Install it (file vcredist_x86.exe) before istalling the SDK (see file readme.txt).

7.6.2 Bonjour Core Services 1.0.4

This needs to be installed for FLIR A3XX and A6XX/SC6XX cameras. The file name of the installer is “BonjourSetup.exe”.

7.6.3 FLIR Device Drivers

This needs to be installed for all cameras

7.6.4 Ethernet Bus Drivers

It is recommended that these drivers are installed for FLIR GEV cameras (FLIR A3X5 and A615/SC6X5). The filename of the installer is **FLIR eBus Package.exe**.

8 Reference section

8.1 About the camera control

8.1.1 Description

Communications between the LabVIEW code and infrared cameras are provided by an ActiveX contained in the file CamCtrl.ocx.

You can use it to switch camera measurement range, control the camera image filtering, view camera status etc. You can also retrieve images and temperature tables.

8.1.2 File names

License file: CamCtrl.lic
Binary load file: CamCtrl.ocx
Type library: CamCtrl.tlb

8.1.3 Interfaces

The ActiveX Control Module contains one interface named **FLIR SDK 2.6 Camera Control**.

8.1.4 Camera control properties, methods and events

This control has methods, properties and events by which you can interact with it. The methods and properties allow you to give commands to the control and to retrieve information from it. The events can tell you that something important has happened, for instance that the user has pressed the disconnect button.

The distinction between methods and properties is quite subtle. Properties can be assigned one single value, which methods normally can not. Methods can take parameters, which properties normally can not. The intermediate case, a property with parameters, exists and is handled by this guide as a method because that is the way in which it is regarded by Visual Basic.

This reference guide lists the properties, methods and events in separate sections, in alphabetic order.

8.1.5 Data types

The data types described in this reference manual are those used by the Microsoft® C/C++ compiler. The Visual Basic interpreter uses other names for those data types. See the table below for compatible data types.

8.2 Properties

C/C++	LabVIEW
Float	SGL
Short	I16
BSTR	String
Variant	Variant
Long	I32
Double	DBL

8.2.1 Version Property

Returns the camera control version string.

Syntax:

version = *object.***Version**

Item	Description	Value
object	Control object name	For example **CamCtrl**
Version	BSTR	E.g "FLIR Camera Control, ver 2.100"

8.3 Methods

8.3.1 AboutBox Method

You can use the **AboutBox** method to bring up the **About** box of the camera control.

Syntax:

*Object.***AboutBox**

Item	Description	Value
Object	Control object name	For example **CamCtrl**

8.3.2 Connect Method

Connect with the camera using the specified device, communication interface and port. The port value is not used. You should wait for the camera **Connected** event before acquiring any images or setting/getting properties.

Syntax:

Status = *Object.***Connect(** camera, port, device, interface, server **)**

Item	Description	Value
Object	Control object name	For example **CamCtrl**
Status	Short Return status	0 = OK If nonzero then connection has failed. Use **GetError** method to convert status code to string.
Camera	Short Camera type	0 = ThermaCAM SC2000/SC300 (not supported) 1 = THV 900 (not supported) 2 = THV 1000 (not supported) 3 = ThermaCAM SC1000 (not supported) 4 = ThermaCAM S40/S45/S60/S65 5 = Thermovision A20/A40 6 = Indigo Merlin 7 = Indigo Phoenix 8 = Indigo Omega 9 = Cumulus SC4000/SC6000 10 = ThermaCAM SC640/CS660 11 = FLIR A320/A300/A310 12 = FLIR A325(A320G)/A315/SC305/SC325 13 = FLIR GF320/GF309 14 = FLIR T-series 15 = FLIR A615/SC645/SC655 16 = FLIR Exx series
Port	Short. Port to use for communications interface.	0 = Automatic selection of port
Device	Short Image source device	**1** FLIR PCCard **2** ITEX IC-DIG 16 **3** FireWire 16-bit images **4** FireWire 8-bit images **5** Ethernet 16-bit images **6** Ethernet 8-bit images **7** IR-FlashLink **8** iPort/GEV **9** USB Video

Item	Description	Value
Interface	Short. Communications interface type.	0. File Only (None) 1. RS232 (Serial) 2. TCP/IP (Socket) 3. AV/C (Firewire) 4.Gigabit (Pleora) 5. AXIS (Axis HTTP 2.x) 6. UVC (USB video class)
Server	BSTR. Camera network address (IP address)	Required if communications interface is AXIS or if image source device is Ethernet (8-bit images). The network address of a camera can be found by using the camera GUI (only for A20/A40). If device is FireWire™ and communication interface is FireWire™, then you may optionally specify the camera serial number in order to connect to a specific camera on the FireWire™ bus.

8.3.3 Disconnect Method

Disconnects the camera and exits the digital transfer mode. You should always disconnect the camera before shutting down your application.

Syntax:

Status = *Object.***Disconnect( )**

Item	Description	Value
Object	Control object name	For example **CamCtrl**
Status	Short.	Return status code.

8.3.4 DoCameraAction Method

Perform a specific camera action as listed below.

Syntax:

Status = *Object.***DoCameraAction(** Action **)**

Item	Description	Value
Object	Control object name	For example **CamCtrl**
Status	Short	Return status code.

Item	Description	Value
Action	Short Action codes Set recording condition properties (ID 27–40) before starting a recording.	0 = Start recording 1 = Stop recording 2 = Enable recording 3 = Disable recording 4 = Pause recording 5 = Resume paused recording 6 = Single snapshot recording 7 = Show recording settings dialog box 8 = Internal image correction (shutter maneuver) 9 = External image correction 10 = Auto adjust 11 = Clear list of recorded files 12 = Auto focus 13 = Show camera information dialog box 14 = Show device status dialog box 15 = Reload calibration from camera 16 = Simulate recording key trig 19 = Save camera settings file (camera type 4 and 5) 20 = Restore settings file (camera types 4 and 5)

8.3.5 EmissCalc Method

Calculates a new emissivity factor for a specified pixel. The image pixel position and a known temperature for this position are supplied as input parameters. If successful, a new calculated emissivity factor (float) is returned. If unsuccessful, an error code is returned (short).

Syntax:

eps = Object.**EmissCalc(** *X, Y, knownTemp* **)**

Item	Description	Value
Object	Control object name	For example **CamCtrl**
eps	VARIANT	Short. Error code Float. New calculated emissivity value
X	Long	Image pixel x coordinate
Y	Long	Image pixel y coordinate

Item	Description	Value
Known temperature	Float	Known pixel temperature (in Kelvin)

8.3.6 GetAbsLUT Method

This method is now obsolete and should not be used.

8.3.7 GetObjLUT Method

Gets a pixel translation table. The table translates absolute image pixels to object pixels. If successful, a memory block will be allocated for the translation table, and it is the responsibility of the caller to de-allocate the memory. The table size depends on the *tableType* parameter.

Syntax:

table = *object.***GetObjLUT(** tableType **)**

Item	Description	Value
Object	Control object name	For example **CamCtrl**
Table	VARIANT	A 1-dimensional array of single precision float translating absolute image pixels to object image pixels.
tableType	Short	1 = Table size 65536 (16-bit absolute image pixels) 2 = Table size 32768 (15-bit absolute image pixels)

8.3.8 GetCameraProperty Method

Gets specific camera property.

Syntax:

Property = *Object.***GetCameraProperty(** Id **)**

Item	Description	Value
Object	Control object name	For example **CamCtrl**
Property	VARIANT	Camera property value
Id	Short	Property id. See table below.

ID	R/W	Type	Description
0	R/W	Float	Reflected temperature (in Kelvin) Range 0-5000
1	R/W	Float	Atmospheric temperature (in Kelvin) Range 0-5000
2	R/W	Float	Object distance (in meter) Range 0-10000
3	R/W	Float	Object emissivity. Range 0.01–1.00
4	R/W	Float	Relative humidity. Range 0–0.99
5	R/W	Float	Reference temperature (in Kelvin) Range 0-5000
6	R/W	Float	External optics temperature (in Kelvin) Range 0-5000
7	R/W	Float	External optics transmission Range 0.01-1.00
8	R/W	Float	Low Scale Limit (in Kelvin) Range 0-5000
9	R/W	Float	High Scale Limit (in Kelvin) Range 0-5000
10	R/W	Short	Temperature presentation unit 0 = Celsius 1 = Fahrenheit 2 = Kelvin
11	R/W	Short	Distance presentation unit 0 = Meter 1 = Foot
12	R/W	Short	Measurement range array index
13	R/W	BSTR	Focus motor state ("far", "near" or "stop")
14	R/W	Long	Focus absolute position (range depends on camera type)
15	R/W	BSTR	Cooler state ("on", "off", "standby", "cooling")
16	R	BSTR	Battery status
17	R/W	BSTR	Current camera palette
18	R/W	Short	Deprecated.

ID	R/W	Type	Description
19	R	BSTR	Current filter name
20	R/W	Short	Deprecated.
21	R	BSTR	Camera model name
22	R	Short	Current camera type (see Connect Method for values)
23	R	BSTR	Current lens name
24	R	Short	Device type (see Connect Method for values)
25	R	Short	Communications port (see Connect Method for values)
26	R	BSTR	Video mode ("NTSC" or "PAL")
27	R/W	Short	Recording store condition 0 = User 1 = Highest 2 = Every N:th image 3 = At time interval 4 = At external trig
28	R/W	Short	Recording stop condition 0 = User 1 = After time interval 2 = After N images 3 = At external trig
29	R/W	Short	Recording start condition 0 = User 1 = At absolute time 2 = At external trig
30	R	Short	Recording state 0 = Disabled 1 = Waiting for start 2 = Active 3 = Paused
31	R/W	Short	Source for recording trigs or image marking trigs. 0 = External device or camera 1 = COM port 2 = LPT port (LPT not supported on NT platforms) 3 = None

ID	R/W	Type	Description
32	R/W	Short	Recording trig port Range 1-256
33	R/W	Short	Recording file format 0 = Multiple proprietary image files 1 = Sequence file format (*.seq) 2 = Multiple public image files (*.fpf)
34	R/W	Double	Recording start value. Delay in seconds if start condition = 2. Absolute time in days from midnight, 30 December 1899, if start condition = 1.
35	R/W	Double	Recording store value. Image interval if store condition = 2. Time interval in seconds if store condition = 3.
36	R/W	Double	Recording stop value. Time interval in seconds if stop condition = 1. Number of images to record if stop condition = 2. Delay in seconds if stop condition = 3.
37	R/W	BSTR	Recording file base name. Max 10 characters allowed.
38	R/W	Short	Presentation mode 0 = GetImage disabled during active recording 1 = Enabled
39	R/W	BSTR	Recording directory path. E. g. "C:\Images"
40	R	Array (BSTR)	List of recorded files. Use DoCameraAction method to clear this list.

ID	R/W	Type	Description
41	R/W	Short	Noise reduction ThermaCAM™ SC2000: 0-2 = Off 3-5 = Normal >5 = High ThermoVision™ A series: 0–2 = Off >3 = On ThermaCAM™ S series: 0–2 = None 3–5 = Low >5 = High FLIR A3X0, A3X5/SC3X5, A615/SC6X5: Not supported.
42	R/W	Float	Zoom factor Range 1.00-8.00
43	R/W	Double	Frame rate or image speed (in Hertz)
44	R/W	Short	Deprecated.
45	R	BSTR	Calibration title
46	R	Array (BSTR)	List of measurement ranges (in Kelvin). Use this property to determine the number of available measurement ranges. Use the array index to modify the measurement range (property 12)
47	R/W	Short	Automatic shutter. 0=Off 1=On, managed by camera control software 2=On, managed by embedded camera software (SDK default at Connect).
48	R/W	Short	Deprecated.
49	R/W	Short	Scale or overlay graphics visibility (in camera video signal) 0 = Not visible 1 = Visible
50	R/W	Short	Offset Correction Range -500 to +500

ID	R/W	Type	Description
51	R/W	Short	Aperture Range 1-5.
52	R/W	Short	Reserved for internal use
53	R/W	BSTR	IR Source File (absolute path). Only used if image source is file device.
54	R/W	Short	Tooltip visibility 0 = Off 1 = On
55	R/W	Short	Reserved for internal use
56	R/W	Float	Override calculated transmission with estimated value. Range 0-1.
57	R/W	Long	Recording file index
58	R/W	Short	Image rotation 0 = Normal 1 = Horizontal 2 = Vertical 3 = Diagonally
59	R	BSTR	Recording file extension for single file.
60	R	Array (BSTR)	List of available camera palettes
61	R/W	Short	Camera default initialization. Set before connecting. 0 = Disabled 1 = Enabled (default)
62	R/W	Array	Text comments (only for camera type 0, 4, 5, 9-12)
63	R/W	BSTR	Resource path (only for camera type 4, 5, 10, 11, 12, and 13-16)
64	R/W	Any	Resource value (only for camera type 4, 5, 10, 11, 12 and 13-16)
65	R/W	Long	Camera ID (only for camera type 5 and 11). Range 1–999.
66	R	Long	Image line width (in pixels)
67	R	Long	Image height (number of rows or lines)

ID	R/W	Type	Description
68	R	Short	Image pixel size 0 = 16-bit 1 = 8-bit
69	R	Short	Camera status 0 = Connected 1 = Disconnected 2 = Connecting phase 3 = Connection broken 4 = Disconnecting phase
70	W	Short	DirectX viewer 0 = Off 1 = On 2 = Show property page
71	R/W	Short	Image mode 0 = Signal (default) 1 = Temperature 0.1 K 2 = Temperature 0.01 K
72	R/W	Short	Multicast 0 = Use unicast 1 = Use multicast connection (device type 4 and 6) Must be set before connecting.
73	R/W	Short	Deprecated
75	R	Array (double)	List of available frame rates
76	R	Long	Number of images in current image sequence file
77	R/W	Long	Current image number in image sequence file
78	R/W	Short	1 = Wrap to first image in sequence 0 = Do not wrap at end of sequence
79	R/W	Short	0=No downsample 1=Downsample image (only for camera type 5)
80	R	BSTR	Serial number of camera (from image file or camera)
81	R	Long	Deprecated.

ID	R/W	Type	Description
82	R/W	Short	0 = Disable correction 1 = Enable emissivity corr. 2 = Enable distance corr.
83	R/W	Short	1 = Override source object parameters 0 = Source decides object parameters
84	R/W	Short	1 = Override source scale parameters 0 = Source decides scaling parameters
85	R/W	Short	0 = Normal mode 1 = Silent mode (no popups)
86	R	Short	1 = Cameras has autofocus 0 = Camera does not have autofocus
87	R/W	Short	1=Subscribe to resource path 0=Unsubscribe to resource path Resource path is set using property 63.
88	R	DATE	File device: Image file time stamp Image acquisition device: Time stamp of last image acquisition
89	R	Short	File device: Millisecond part of image file time stamp Image acquisition device: Millisecond part of last image acquisition
90	R	Long	File device: Image file trig count Image acquisition device: Current trig count of image source
91	R/W	Short	Camera file format (supported for camera type 5, 11 and 12) 0 = JPEG and non-compressed IR pixel data (56 kB) 1 = JPEG and PNG-compressed IR pixel data (19 kB) 2 = JPEG without IR data (16 kB) 3 = Only IR and pixel data not compressed (40 kB) 4 = Only IR and pixel data PNG-compressed (4 kB)
92	R/W	Short	File naming used when snapshot recordings are performed in the camera. 0 = Use normal naming (base name + index) 1 = Use current date and time in file name

ID	R/W	Type	Description
93	R/W	Long	Image request timeout (in milliseconds)
94	R/W	Long	Timeout (in milliseconds) for property 64

8.3.9 GetError Method

Converts an status code or error code to a formatted error string.

Syntax:

errorString = *object.***GetError(** errCode **)**

Item	Description	Value
Object	Control object name	For example **CamCtrl**
errorString	BSTR	Error string depending on errCode.
errCode	Short	Return code from other methods.

Status or error code	Explanation
0	OK. No error.
-1	Unspecified error
1	Device not present
2	Device busy
3	Device driver missing
4	Device driver must be updated
5	Failed to load device firmware
6	Failed to configure device. Resource conflict
8	Service Control Manager error
9	Failed to establish a camera control connection
10	Control connection closed
11	Cannot allocate image buffer
12	Invalid image
13	Device hardware error
14	Timeout waiting for image

Status or error code	Explanation
15	Camera configuration error
16	Image acquisition aborted
17	Image source is not initiated
21	Failed to initiate device
22	Failed to open or access file
24	File media full
25	File format not recognized
26	Known temperature is too close to reflected temperature
27	Known and shown temperature are on different sides of reflected temperature
28	Requested function not supported
29	Invalid parameter

8.3.10 GetImage Method

Gets a row-oriented image from the camera. If successful, a memory block will be allocated for the image pixels, and it is the responsibility of the caller to deallocate the memory. The image size depends on selected camera type.

Syntax:

Image = *Object*.**GetImage(** imageType **)**

Item	Description	Value
Object	Control object name	For example **CamCtrl**
Image	VARIANT	One of the following: ▪ A 2-dimensional array with image pixels. Pixel format depends on the imageType parameter. ▪ Return error code (short)
imageType	Short	0 = Absolute image pixels (16-bit unsigned integer) 2 = Object signal pixels (single precision float) 3 = Temperature pixels (single precision float) 4 = Relative temperature pixels (8-bit unsigned integer)

8.3.11 GetImages Method

Gets a sequence of images from the camera. An array of image pointers is supplied to the method. It is the responsibility of the caller to allocate the space needed for each image. The image structure is row-oriented. Use the properties for image width (66) and height (67) in order to calculate the space needed for each image. A camera event (**Image captured** event) is sent when the first image has been captured.

Syntax:

Status = *Object.***GetImages(** imageType, imageArray, imageSize **)**

Item	Description	Value
Object	Control object name	For example **CamCtrl**.
Status	VARIANT	Return code.
imageType	Short	0 = Absolute image pixels (16-bit unsigned integer) 2 = Object signal pixels (single precision float) 3 = Temperature pixels (single precision float) 4 = Relative temperature pixels (8-bit unsigned integer)
imageArray	VARIANT (array of 32-bit pointers)	Pointer array of pre-allocated images. Each image consists of at least imageSize bytes.
imageSize	Long	Size in bytes of each image

8.3.12 GetLUT Method

Gets a temperature translation table. The table translates absolute image pixels to temperature. If successful, a memory block will be allocated for the translation table, and it is the responsibility of the caller to deallocate the memory. The table size depends on the *tableType* parameter. The 8-bit LUT depends on the camera temperature scale low and high properties.

Syntax:

Table = *object.***GetLUT(** tableType **)**

Item	Description	Value
Object	Control object name	For example **CamCtrl**

Item	Description	Value
Table	VARIANT	A 1-dimensional array of single precision floats translating absolute image pixels to temperature (in Kelvin).
tableType	Short	0 = Table size 256 (8-bit pixels) 1 = Table size 65536 (16-bit pixels) 2 = Table size 32768 (15-bit pixels)

8.3.13 MLGetImages Method

Get array of images. This method is especially designed for the MATLAB example code.

Syntax:

imageArray = Object.**MLGetImages(** *imageType, imageWidth, imageHeight, image* **)**

Item	Description	Value
Object	Control object name	For example **CamCtrl**
imageArray	VARIANT	Array of images with requested pixel type
imageType	Short	0 = Absolute image pixels (16-bit unsigned integer) 2 = Object signal pixels (single precision float) 3 = Temperature pixels (single precision float) 4 = Relative image pixels (8-bit unsigned integer)
imageWidth	Short	Image width in pixels
imageHeight	Short	Image height in pixels
image	Short	Number of images to record

8.3.14 SetCameraProperty Method

Set specific camera property.

SEE ALSO: For details about which properties can be modified, see section 8.3.8 – GetCameraProperty Method on page 54

Syntax:

Status = *Object*.**SetCameraProperty(** Id, Property **)**

Item	Description	Value
Object	Control object name	For example CamCtrl.
Status	Short	Return code
Id	Short	Camera property id **SEE ALSO:** For details about which properties can be modified, see section 8.3.8 – GetCameraProperty Method on page 54
Property	VARIANT	Camera property value

8.3.15 SetImage Method

Sets an image with absolute image pixel data. The image should be row-oriented.

Syntax:

Status = *Object*.**SetImage(** image **)**

Item	Description	Value
Object	Control object name	For example **CamCtrl**
Image	VARIANT	A 2-dimensional array with absolute image pixels in 16-bit unsigned integer format.
Status	Short	Return code

8.3.16 SetEmissMap Method

Set an image emissivity correction map. The correction map should be row-oriented and of the same size as the current image size. Use property 82 to enable or disable the correction function. The emissivity correction is applied when a temperature image is requested and the source image is a 16-bit signal image. The emissivity correction can be used when your source image has objects with highly varying emissivity factors.

Syntax:

Status = *Object*.**SetEmissMap(** Map **)**

Item	Description	Value
Object	Control object name	For example **CamCtrl**
Status	Short	Return code

Item	Description	Value
Map	VARIANT	A 2-dimensional array with emissivity values in float format, one for each image pixel. The individual emissivity values must be in the range 0.01 to 1.00.

8.3.17 SetDistanceMap Method

Set an image distance correction map. The correction map should be row-oriented and of the same size as the current image size. Use property 82 to enable or disable the correction function. The distance correction is applied when a temperature image is requested and the source image is a 16-bit signal image. The distance correction can be used when your source image has objects with varying distance factors. This method will overwrite any existing emissivity correction map.

Syntax:

Status = *Object*.**SetDistanceMap(** Map **)**

Item	Description	Value
Object	Control object name	For example CamCtrl.
Status	Short	Return code
Map	VARIANT	A 2-dimensional array with distance values in float format, one for each image pixel. The individual distance values must be in the range 0 to 9999 (meters).

8.3.18 SubmitCamCommand Method

Submits a user command to the camera. The response from the camera is returned in the **CamCmdReply** event. Do not use this method for camera types 4, 5 and 10-16. Camera types 4, 5 and 10-16 must use properties 63 and 64 for user commands.

Syntax:

Status = *Object*.**SubmitCamCommand(** cmd **)**

Item	Description	Value
object	Control object name	For example **CamCtrl**
status	Short	Return code
cmd	BSTR	Camera command string

8.3.19 ToTemperature Method

Converts a given absolute pixel value to temperature in Kelvin.

Syntax:

Temperature = *Object*.**ToTemperature(** abspix, eps **)**

Item	Description	Value
Object	Control object name	For example **CamCtrl**
Temperature	Float	Temperature in Kelvin
Abspix	Long	Absolute pixel value
Eps	Float	Emissivity factor (0.0-1.0). If 0 then use image emissivity.

8.4 Events

8.4.1 CameraEvent Event

The **CameraEvent** event occurs when a camera connection changes state. Events can also be thrown for camera state changes, which affect the image distribution (8 and 9).

Syntax:

Private Sub *object*_**CameraEvent** ([id **As Short**])

Item	Description	Value
Object	Control object name	For example CamCtrl

Item	Description	Value
Id	Short. Event identifier	2 = Device is connected 3 = Device is disconnected 4 = Device connection broken 5 = Device reconnected from broken connection 6 = Device is in disconnecting phase 7 = Auto adjust event 8 = Start of shutter operation 9 = End of shutter operation 10 = LUT table updated 11 = Recording conditions changed 12 = Image captured 13 = All camera settings retrieved 14 = Frame rate table available (see property 75) 15 = Frame rate change completed (after setting property 43) 16 = Measurement range table available (see property 46) 17 = Measurement range change completed (after setting property 12) 18 = Image size has changed

8.4.2 CamCmdReply Event

The **CamCmdReply** event occurs when the camera control receives a response from a user command issued from the **SubmitCamCommand** Method.

Syntax:

Private Sub *object*_**CamCmdReply** ([response **As Bstr**])

Item	Description	Value
object	Control object name	For example CamCtrl
response	Command response	Response from call to method SubmitCamCommand

8.4.3 ResourceChanged Event

The **ResourceChanged** event occurs when the camera control receives a resource-changed notification from the camera. An active resource subscription is required in order to receive this event. First setting a resource path using property 63 and then

activating the subscription by setting property 87 will establish an active subscription. This event can only be fired for camera type 5, 11 and 12 using a TCP/IP communications interface.

Syntax:

Private Sub *object*_**ResourceChanged** ([resource **As Bstr**], [value **As Variant**])

Item	Description	Value
object	Control object name	For example CamCtrl
resource	BSTR	Resource path
value	VARIANT	New resource value

9 FLIR Public File image format

9.1 General information

The "xxxx.fpf" files consist of a header followed by a matrix of single precision IEEE floating-point values, each representing one point of the image. A C-style description of the header layout can be found in the header file fpfimg.h, available in the installation directory. The image point values are stored starting from the top left corner, row by row. The FLIR camera control can only save FPF images with floating point temperature values

9.2 Basic data

Char	8 bit	Often represents ASCII characters, may represent an 2's complement 8 bit integer (-128--+127)
Unsigned char	8 bit	8 bit integer number (0--255)
Short	16 bit	16 bit integer (2's complement)
Unsigned short	16 bit	16 bit integer
Long	32 bit	32 bit integer (2's complement)
Unsigned long	32 bit	32 bit integer
Float	32 bit	IEEE floating point number, sign + 23 bit mantissa + 8 bit exponent, Representing numbers in the range +/- 1038
Char[<len>]	Len * 8 bit	ASCII character string, most certainly terminated with the NUL character (= 0)
Int	32 bit	32 bit integer (2's complement)

Multiple byte data types are stored with the least significant byte first.

9.3 The whole header data structure (size 892 bytes)

```
typedef struct
{
   FPF_IMAGE_DATA_T  imgData;
   FPF_CAMDATA_T     camData;
   FPF_OBJECT_PAR_T  objPar;
   FPF_DATETIME_T    datetime;
   FPF_SCALING_T     scaling;
```

```
   long  spareLong[32];    /* = 0 */
} FPFHEADER_T;
```

9.4 The image data structure (120 bytes)

```
typedef struct
{
   char fpfID[32];                /*  "FLIR Public Image Format" */
   unsigned long  version;        /*  = 2 */
   unsigned long  pixelOffset;    /*  Offset to pixel values from
                                      start of fpfID. */
   unsigned short ImageType;      /*  Temperature        = 0,
                                      Diff Temp          = 2,
                                      Object Signal      = 4,
                                      Diff Object Signal = 5, etc */
   unsigned short pixelFormat;    /*  0 = short integer  = 2 bytes
                                      1 = long integer   = 4 bytes
                                      2 = float          = 4 bytes
                                      3 = double         = 8 bytes*/
   unsigned short xSize;
   unsigned short ySize;
   unsigned long  trig_count;     /* external trig counter */
   unsigned long  frame_count;    /* frame number in sequence */
   long  spareLong[16];           /* = 0 */
} FPF_IMAGE_DATA_T;
```

9.5 The camera data structure (360 bytes)

```
/*  String lengths    */
#define FPF_CAMERA_TYPE_LEN   31   /* Camera name string */
#define FPF_CAMERA_PARTN_LEN  31   /* Camera part number string */
#define FPF_CAMERA_SN_LEN     31   /* Scanner serial number string */
#define FPF_LENS_TYPE_LEN     31   /* Lens name string */
#define FPF_LENS_PARTN_LEN    31   /* Lens part number string */
#define FPF_LENS_SN_LEN       31   /* Lens serial number string */
#define FPF_FILTER_TYPE_LEN   31   /* Filter name string */
#define FPF_FILTER_PARTN_LEN  31   /* Filter part number string */
#define FPF_FILTER_SN_LEN     31   /* Filter serial number string */
typedef struct
{
    char camera_name[FPF_CAMERA_TYPE_LEN+1];
    char camera_partn[FPF_CAMERA_PARTN_LEN+1];
    char camera_sn[FPF_CAMERA_SN_LEN+1];

    float camera_range_tmin;
    float camera_range_tmax;

    char lens_name[FPF_LENS_TYPE_LEN+1];
    char lens_partn[FPF_LENS_PARTN_LEN+1];
    char lens_sn[FPF_LENS_SN_LEN+1];
    char filter_name[FPF_FILTER_TYPE_LEN+1];
    char filter_partn[FPF_FILTER_PARTN_LEN+1];
    char filter_sn[FPF_FILTER_SN_LEN+1];
   long  spareLong[16];            /* = 0 */
}FPF_CAMDATA_T;
```

9.6 The object parameters data structure (104 bytes)

```
typedef struct
{
   float emissivity;        /* 0 - 1 */
   float objectDistance;    /* Meters */
   float rflTemp;           /* Reflected temperature in Kelvin */
   float atmTemp;           /* Atmospheric temperature in Kelvin */
   float relHum;            /* 0 - 1 */
```

```
   float compuTao;          /* Computed atmospheric transmission */
   float estimTao;          /* Estimated atmospheric transmission */
   float refTemp;           /* Reference temperature in Kelvin */
   float extOptTemp;        /* Kelvin */
   float extOptTrans;       /* 0 - 1 */
   long  spareLong[16];     /* = 0 */
} FPF_OBJECT_PAR_T;
```

9.7 The date and time data structure (92 bytes)

```
typedef struct
{
   int Year;
   int Month;
   int Day;
   int Hour;
   int Minute;
   int Second;
   int MilliSecond;
   long  spareLong[16];            /* = 0 */
} FPF_DATETIME_T;
```

9.8 The scaling data structure (88 bytes)

```
typedef struct
{
   float tMinCam;         /* Camera scale min, in current output */
   float tMaxCam;         /* Camera scale max */
   float tMinCalc;        /* Calculated min (almost true min) */
   float tMaxCalc;        /* Calculated max (almost true max) */
   float tMinScale;       /* Scale min */
   float tMaxScale;       /* Scale max */
   long  spareLong[16];   /* = 0 */
} FPF_SCALING_T;
```

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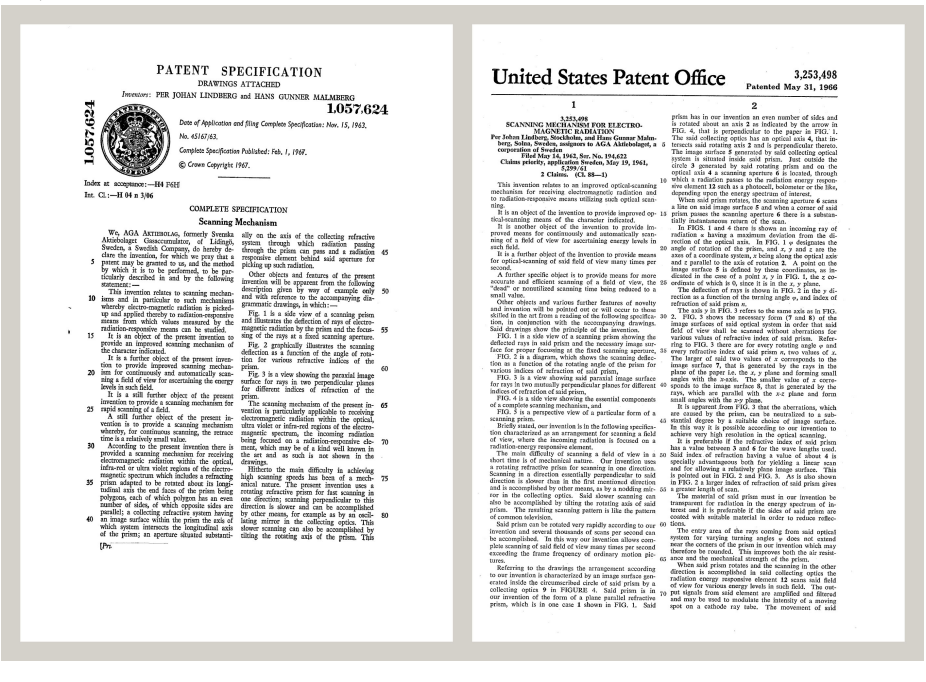
10 About FLIR Systems

FLIR Systems was established in 1978 to pioneer the development of high-performance infrared imaging systems, and is the world leader in the design, manufacture, and marketing of thermal imaging systems for a wide variety of commercial, industrial, and government applications. Today, FLIR Systems embraces five major companies with outstanding achievements in infrared technology since 1958—the Swedish AGEMA Infrared Systems (formerly AGA Infrared Systems), the three United States companies Indigo Systems, FSI, and Inframetrics, and the French company Cedip. In November 2007, Extech Instruments was acquired by FLIR Systems.

T638608;a1



PATENT SPECIFICATION

DRAWINGS ATTACHED

Inventors: PER JOHAN LINDBERG and HANS GUNNER MALMBERG

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Date of Application and filing Complete Specification: Nov. 15, 1963.
No. 45167/63.

Complete Specification Published: Feb. 1, 1967.

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Index at acceptance:—H4 [G6F

Int. Cl.:—H 04 n 3/06

COMPLETE SPECIFICATION

Scanning Mechanism

We, AGA AKTIEBOLAG, formerly Svenska Aktiebolaget Gasaccumulator, of Lidingö, Sweden, a Swedish Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to scanning mechanisms and in particular to such mechanisms whereby electro-magnetic radiation is picked-up and applied thereby to radiation-responsive means from which values measured by the radiation-responsive means can be studied.

It is an object of the present invention to provide an improved scanning mechanism of the character indicated.

It is a further object of the present invention to provide improved scanning mechanism for continuously and automatically scanning a field of view for ascertaining the energy levels in such field.

It is a still further object of the present invention to provide a scanning mechanism for rapid scanning of a field.

A still further object of the present invention is to provide a scanning mechanism whereby, for continuous scanning, the retrace time is a relatively small value.

According to the present invention there is provided a scanning mechanism for receiving electromagnetic radiation within the optical, infra-red or ultra violet regions of the electromagnetic spectrum which includes a refracting prism adapted to be rotated about its longitudinal axis the end faces of the prism being polygons, each of which polygon has an even number of sides, of which opposite sides are parallel; a collecting refractive system having an image surface within the prism the axis of which system intersects the longitudinal axis of the prism; an aperture situated substantially on the axis of the collecting refractive system through which radiation passing through the prism can pass and a radiation responsive element behind said aperture for picking up such radiation.

Other objects and features of the present invention will be apparent from the following description given by way of example only and with reference to the accompanying diagrammatic drawings, in which:—

Fig. 1 is a side view of a scanning prism and illustrates the deflection of rays of electromagnetic radiation by the prism and the focussing of the rays at a fixed scanning aperture.

Fig. 2 graphically illustrates the scanning deflection as a function of the angle of rotation for various refractive indices of the prism.

Fig. 3 is a view showing the paraxial image surface for rays in two perpendicular planes for different indices of refraction of the prism.

The scanning mechanism of the present invention is particularly applicable to receiving electromagnetic radiation within the optical, ultra violet or infra-red regions of the electromagnetic spectrum, the incoming radiation being focused on a radiation-responsive element, which may be of a kind well known in the art and as such is not shown in the drawings.

Hitherto the main difficulty in achieving high scanning speeds has been of a mechanical nature. The present invention uses a rotating refractive prism for fast scanning in one direction; scanning perpendicular to this direction is slower and can be accomplished by other means, for example as by an oscillating mirror in the collecting optics. This slower scanning can also be accomplished by tilting the rotating axis of the prism. This

[Pr

United States Patent Office

3,253,498

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3,253,498

SCANNING MECHANISM FOR ELECTROMAGNETIC RADIATION

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Filed May 14, 1962, Ser. No. 194,622

Claims priority, application Sweden, May 19, 1961, 5,299/61

2 Claims. (Cl. 88—1)

This invention relates to an improved optical-scanning mechanism for scanning electromagnetic radiation and to radiation-responsive means utilizing such optical scanning.

It is an object of the invention to provide improved means for continuously and automatically scanning of a field of view for ascertaining energy levels in such field.

It is a further object of the invention to provide means for optical-scanning of said field of view many times per second.

A further specific object is to provide means for more accurate and efficient scanning of a field of view, the "dead" or nonutilized scanning time being reduced to a small value.

Other objects and various further features of novelty and invention will be pointed out or will occur to those skilled in the art from a reading of the following specification, in conjunction with the accompanying drawings. Said drawings show the principle of the invention.

FIG. 1 is a side view of a scanning prism showing the deflected rays in said prism and the necessary image surface for proper focussing at the fixed scanning aperture.

FIG. 2 is a diagram, which shows the scanning deflection as a function of the rotating angle of the prism for various indices of refraction of said prism,

FIG. 3 is a view showing said paraxial image surface for rays in two mutually perpendicular planes for different indices of refraction of said prism,

FIG. 4 is a side view showing the essential components of a complete scanning mechanism, and

FIG. 5 is a perspective view of a particular form of a scanning prism.

Briefly stated, our invention is in the following specification characterized as an arrangement for scanning a field of view, where the incoming radiation is focused on a radiation-energy responsive element.

The main difficulty of scanning a field of view in a short time is of mechanical nature. Our invention uses a rotating refractive prism for scanning in one direction. Scanning in a direction essentially perpendicular to said direction is slower than in the first mentioned direction and is accomplished by other means, as by a nodding mirror in the collecting optics. Said slower scanning can also be accomplished by tilting the rotating axis of said prism. The resulting scanning pattern is like the pattern of common television.

Said prism can be rotated very rapidly according to our invention and several thousands of scans per second can be accomplished. In this way our invention allows complete scanning of said field of view many times per second exceeding the frame frequency of ordinary motion pictures.

Referring to the drawings the arrangement according to our invention is characterized by an image surface generated inside the circumscribed circle of said prism by a collecting optics 9 in FIGURE 4. Said prism is in our invention of the form of a plane parallel refractive prism, which is in one case 1 shown in FIG. 1. Said

2

prism has in our invention an even number of sides and is rotated about an axis 2 as indicated by the arrow in FIG. 4, that is perpendicular to the paper in FIG. 1. The said collecting optics has an optical axis 4, that intersects said rotating axis 2 and is perpendicular thereto. The image surface 8 generated by said collecting optical system is situated inside said prism. Just outside the circle 3 generated by said rotating prism and on the optical axis 4 a scanning aperture 6 is located, through which a radiation passes to the radiation energy responsive element 12 such as a photocell, bolometer or the like, depending upon the energy spectrum of interest.

When said prism rotates, the scanning aperture 6 scans a line on said image surface 8 and when a corner of said prism passes the scanning aperture 6 there is a substantially instantaneous return of the scan.

In FIGS. 1 and 4 there is shown an incoming ray of radiation 5 having a maximum deviation from the direction of the optical axis. In FIG. 1 α designates the angle of rotation of the prism, and x, y and z are the axes of a coordinate system, x being along the optical axis and z parallel to the axis of rotation 2. A point on the image surface 8 for each value of these angles, as indicated in the case of a point b, is specified, the z coordinate of which is 0, since it is in the x, y plane.

The deflection of rays is shown in FIG. 2 in the y direction as a function of the turning angle, α, and index of refraction of said prism n.

The axis y in FIG. 3 refers to the same axis as in FIG. 2. FIG. 3 shows the necessary focus (f and k) of the image surfaces of said optical system in order that said field of view shall be scanned without aberrations for various values of refractive index of said prism. Referring to FIG. 3 there are for every rotating angle α and every refractive index of said prism n, two values of x. The larger of said two values of x corresponds to the image surface 7, that is generated by the rays in the plane of the paper i.e. the x, y plane and forming small angles with the x-axis. The smaller value of x corresponds to the image surface 8, that is generated by the rays, which are parallel with the x-z plane and form small angles with the x-y plane.

It is apparent from FIG. 3 that the aberrations, which are caused by the prism, can be neutralized to a sufficient degree by a suitable choice of image surface. In this way it is possible according to our invention to achieve very high resolution in the optical scanning.

China, France, Germany, Great Britain, Hong Kong, Italy, Japan, Korea, Sweden, and the USA—together with a worldwide network of agents and distributors—support our international customer base.

FLIR Systems is at the forefront of innovation in the infrared camera industry. We anticipate market demand by constantly improving our existing cameras and developing new ones. The company has set milestones in product design and development such as the introduction of the first battery-operated portable camera for industrial inspections, and the first uncooled infrared camera, to mention just two innovations.

10722703;a2

Figure 10.2 LEFT: Thermovision® Model 661 from 1969. The camera weighed approximately 25 kg (55 lb.), the oscilloscope 20 kg (44 lb.), and the tripod 15 kg (33 lb.). The operator also needed a 220 VAC generator set, and a 10 L (2.6 US gallon) jar with liquid nitrogen. To the left of the oscilloscope the Polaroid attachment (6 kg/13 lb.) can be seen. **RIGHT:** FLIR i7 from 2009. Weight: 0.34 kg (0.75 lb.), including the battery.

FLIR Systems manufactures all vital mechanical and electronic components of the camera systems itself. From detector design and manufacturing, to lenses and system electronics, to final testing and calibration, all production steps are carried out and supervised by our own engineers. The in-depth expertise of these infrared specialists ensures the accuracy and reliability of all vital components that are assembled into your infrared camera.

10.1 More than just an infrared camera

At FLIR Systems we recognize that our job is to go beyond just producing the best infrared camera systems. We are committed to enabling all users of our infrared camera systems to work more productively by providing them with the most powerful

camera–software combination. Especially tailored software for predictive maintenance, R & D, and process monitoring is developed in-house. Most software is available in a wide variety of languages.

We support all our infrared cameras with a wide variety of accessories to adapt your equipment to the most demanding infrared applications.

10.2 Sharing our knowledge

Although our cameras are designed to be very user-friendly, there is a lot more to thermography than just knowing how to handle a camera. Therefore, FLIR Systems has founded the Infrared Training Center (ITC), a separate business unit, that provides certified training courses. Attending one of the ITC courses will give you a truly hands-on learning experience.

The staff of the ITC are also there to provide you with any application support you may need in putting infrared theory into practice.

10.3 Supporting our customers

FLIR Systems operates a worldwide service network to keep your camera running at all times. If you discover a problem with your camera, local service centers have all the equipment and expertise to solve it within the shortest possible time. Therefore, there is no need to send your camera to the other side of the world or to talk to someone who does not speak your language.

10.4 A few images from our facilities

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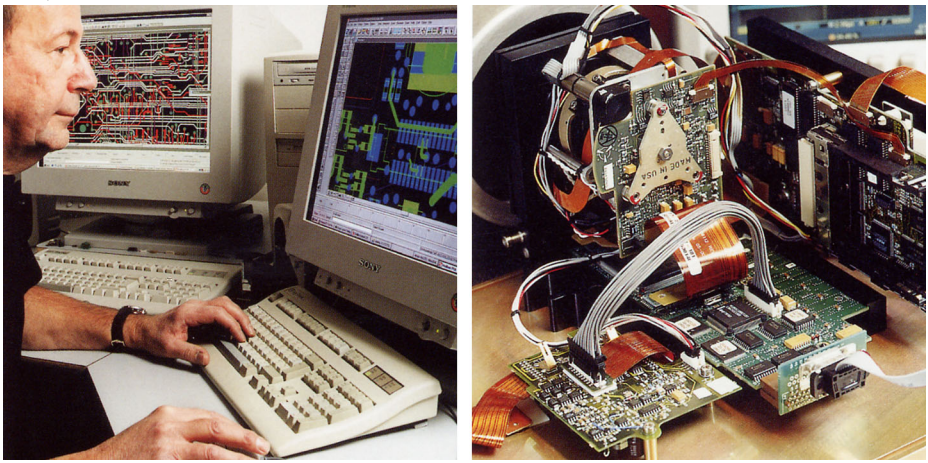

Figure 10.3 LEFT: Development of system electronics; **RIGHT:** Testing of an FPA detector

10401403;a1

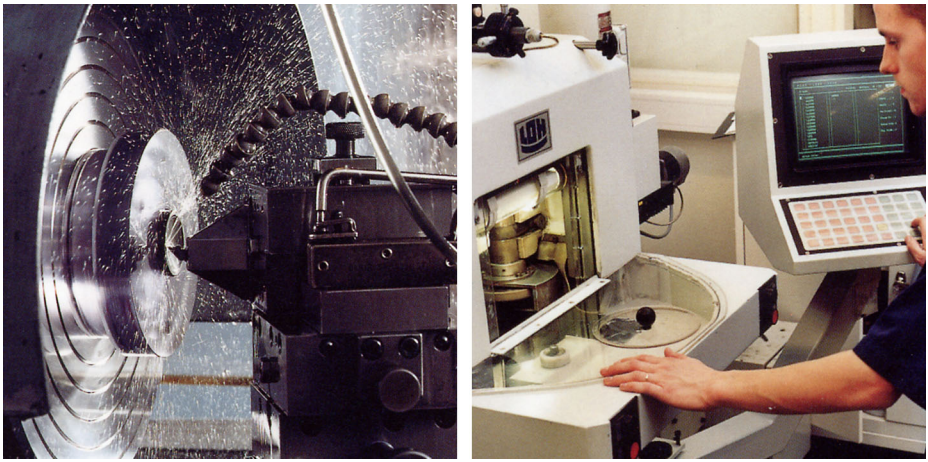

Figure 10.4 LEFT: Diamond turning machine; **RIGHT:** Lens polishing

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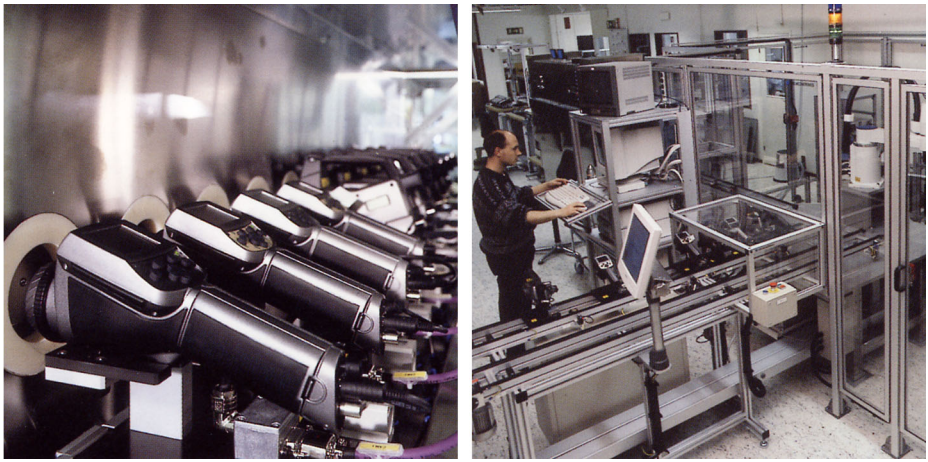


Figure 10.5 LEFT: Testing of infrared cameras in the climatic chamber; **RIGHT:** Robot used for camera testing and calibration

11 Thermographic measurement techniques

11.1 Introduction

An infrared camera measures and images the emitted infrared radiation from an object. The fact that radiation is a function of object surface temperature makes it possible for the camera to calculate and display this temperature.

However, the radiation measured by the camera does not only depend on the temperature of the object but is also a function of the emissivity. Radiation also originates from the surroundings and is reflected in the object. The radiation from the object and the reflected radiation will also be influenced by the absorption of the atmosphere.

To measure temperature accurately, it is therefore necessary to compensate for the effects of a number of different radiation sources. This is done on-line automatically by the camera. The following object parameters must, however, be supplied for the camera:

- The emissivity of the object
- The reflected apparent temperature
- The distance between the object and the camera
- The relative humidity
- Temperature of the atmosphere

11.2 Emissivity

The most important object parameter to set correctly is the emissivity which, in short, is a measure of how much radiation is emitted from the object, compared to that from a perfect blackbody of the same temperature.

Normally, object materials and surface treatments exhibit emissivity ranging from approximately 0.1 to 0.95. A highly polished (mirror) surface falls below 0.1, while an oxidized or painted surface has a higher emissivity. Oil-based paint, regardless of color in the visible spectrum, has an emissivity over 0.9 in the infrared. Human skin exhibits an emissivity 0.97 to 0.98.

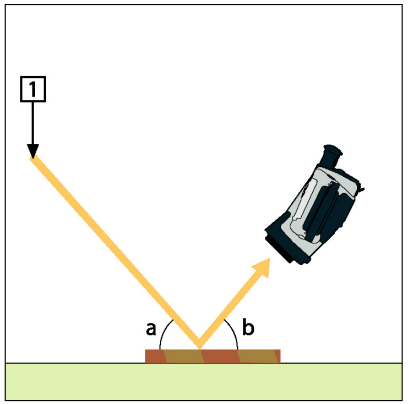
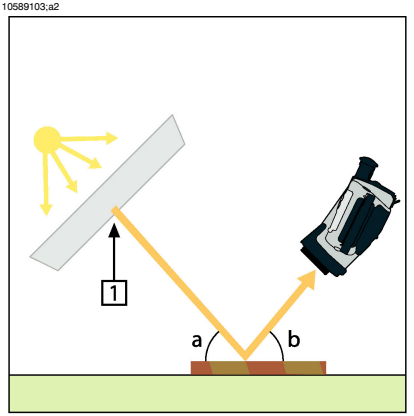
Non-oxidized metals represent an extreme case of perfect opacity and high reflexivity, which does not vary greatly with wavelength. Consequently, the emissivity of metals is low – only increasing with temperature. For non-metals, emissivity tends to be high, and decreases with temperature.

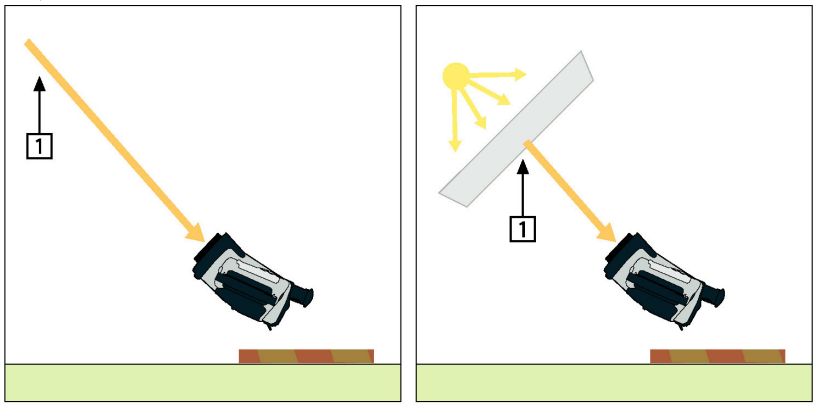
11.2.1 Finding the emissivity of a sample

11.2.1.1 Step 1: Determining reflected apparent temperature

Use one of the following two methods to determine reflected apparent temperature:

11.2.1.1.1 Method 1: Direct method

1	Look for possible reflection sources, considering that the incident angle = reflection angle (a = b). 10588903;a1  **Figure 11.1** 1 = Reflection source
2	If the reflection source is a spot source, modify the source by obstructing it using a piece if cardboard. 10589103;a2  **Figure 11.2** 1 = Reflection source

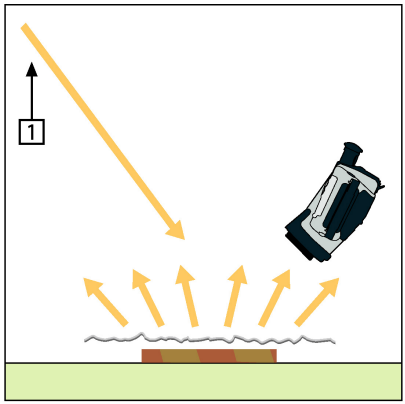
3	Measure the radiation intensity (= apparent temperature) from the reflecting source using the following settings: ▪ Emissivity: 1.0 ▪ D_{obj}: 0 You can measure the radiation intensity using one of the following two methods: 10589003;a2  **Figure 11.3** 1 = Reflection source

Note: Using a thermocouple to measure reflected apparent temperature is not recommended for two important reasons:

- A thermocouple does not measure radiation intensity
- A thermocouple requires a very good thermal contact to the surface, usually by gluing and covering the sensor by a thermal isolator.

11.2.1.1.2 Method 2: Reflector method

1	Crumble up a large piece of aluminum foil.
2	Uncrumble the aluminum foil and attach it to a piece of cardboard of the same size.
3	Put the piece of cardboard in front of the object you want to measure. Make sure that the side with aluminum foil points to the camera.
4	Set the emissivity to 1.0.

5	Measure the apparent temperature of the aluminum foil and write it down. 10727003;a2  **Figure 11.4** Measuring the apparent temperature of the aluminum foil

11.2.1.2 Step 2: Determining the emissivity

1	Select a place to put the sample.
2	Determine and set reflected apparent temperature according to the previous procedure.
3	Put a piece of electrical tape with known high emissivity on the sample.
4	Heat the sample at least 20 K above room temperature. Heating must be reasonably even.
5	Focus and auto-adjust the camera, and freeze the image.
6	Adjust **Level** and **Span** for best image brightness and contrast.
7	Set emissivity to that of the tape (usually 0.97).
8	Measure the temperature of the tape using one of the following measurement functions: ▪ **Isotherm** (helps you to determine both the temperature and how evenly you have heated the sample) ▪ **Spot** (simpler) ▪ **Box Avg** (good for surfaces with varying emissivity).
9	Write down the temperature.
10	Move your measurement function to the sample surface.
11	Change the emissivity setting until you read the same temperature as your previous measurement.
12	Write down the emissivity.

Note:

- Avoid forced convection
- Look for a thermally stable surrounding that will not generate spot reflections
- Use high quality tape that you know is not transparent, and has a high emissivity you are certain of
- This method assumes that the temperature of your tape and the sample surface are the same. If they are not, your emissivity measurement will be wrong.

11.3 Reflected apparent temperature

This parameter is used to compensate for the radiation reflected in the object. If the emissivity is low and the object temperature relatively far from that of the reflected it will be important to set and compensate for the reflected apparent temperature correctly.

11.4 Distance

The distance is the distance between the object and the front lens of the camera. This parameter is used to compensate for the following two facts:

- That radiation from the target is absorbed by the athmosphere between the object and the camera.
- That radiation from the atmosphere itself is detected by the camera.

11.5 Relative humidity

The camera can also compensate for the fact that the transmittance is also dependent on the relative humidity of the atmosphere. To do this set the relative humidity to the correct value. For short distances and normal humidity the relative humidity can normally be left at a default value of 50%.

11.6 Other parameters

In addition, some cameras and analysis programs from FLIR Systems allow you to compensate for the following parameters:

- Atmospheric temperature – *i.e.* the temperature of the atmosphere between the camera and the target
- External optics temperature – *i.e.* the temperature of any external lenses or windows used in front of the camera
- External optics transmittance – *i.e.* the transmission of any external lenses or windows used in front of the camera

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12 History of infrared technology

Before the year 1800, the existence of the infrared portion of the electromagnetic spectrum wasn't even suspected. The original significance of the infrared spectrum, or simply ‘the infrared’ as it is often called, as a form of heat radiation is perhaps less obvious today than it was at the time of its discovery by Herschel in 1800.

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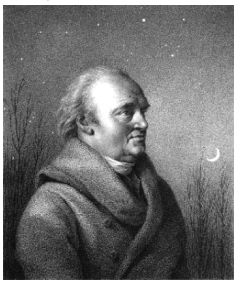

Figure 12.1 Sir William Herschel (1738–1822)

The discovery was made accidentally during the search for a new optical material. Sir William Herschel – Royal Astronomer to King George III of England, and already famous for his discovery of the planet Uranus – was searching for an optical filter material to reduce the brightness of the sun’s image in telescopes during solar observations. While testing different samples of colored glass which gave similar reductions in brightness he was intrigued to find that some of the samples passed very little of the sun’s heat, while others passed so much heat that he risked eye damage after only a few seconds’ observation.

Herschel was soon convinced of the necessity of setting up a systematic experiment, with the objective of finding a single material that would give the desired reduction in brightness as well as the maximum reduction in heat. He began the experiment by actually repeating Newton’s prism experiment, but looking for the heating effect rather than the visual distribution of intensity in the spectrum. He first blackened the bulb of a sensitive mercury-in-glass thermometer with ink, and with this as his radiation detector he proceeded to test the heating effect of the various colors of the spectrum formed on the top of a table by passing sunlight through a glass prism. Other thermometers, placed outside the sun’s rays, served as controls.

As the blackened thermometer was moved slowly along the colors of the spectrum, the temperature readings showed a steady increase from the violet end to the red end. This was not entirely unexpected, since the Italian researcher, Landriani, in a similar experiment in 1777 had observed much the same effect. It was Herschel,

however, who was the first to recognize that there must be a point where the heating effect reaches a maximum, and that measurements confined to the visible portion of the spectrum failed to locate this point.

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Figure 12.2 Marsilio Landriani (1746–1815)

Moving the thermometer into the dark region beyond the red end of the spectrum, Herschel confirmed that the heating continued to increase. The maximum point, when he found it, lay well beyond the red end – in what is known today as the 'infrared wavelengths'.

When Herschel revealed his discovery, he referred to this new portion of the electromagnetic spectrum as the 'thermometrical spectrum'. The radiation itself he sometimes referred to as 'dark heat', or simply 'the invisible rays'. Ironically, and contrary to popular opinion, it wasn't Herschel who originated the term 'infrared'. The word only began to appear in print around 75 years later, and it is still unclear who should receive credit as the originator.

Herschel's use of glass in the prism of his original experiment led to some early controversies with his contemporaries about the actual existence of the infrared wavelengths. Different investigators, in attempting to confirm his work, used various types of glass indiscriminately, having different transparencies in the infrared. Through his later experiments, Herschel was aware of the limited transparency of glass to the newly-discovered thermal radiation, and he was forced to conclude that optics for the infrared would probably be doomed to the use of reflective elements exclusively (i.e. plane and curved mirrors). Fortunately, this proved to be true only until 1830, when the Italian investigator, Melloni, made his great discovery that naturally occurring rock salt (NaCl) – which was available in large enough natural crystals to be made into lenses and prisms – is remarkably transparent to the infrared. The result was that rock salt became the principal infrared optical material, and remained so for the next hundred years, until the art of synthetic crystal growing was mastered in the 1930's.

10399103;a1

Figure 12.3 Macedonio Melloni (1798–1854)

Thermometers, as radiation detectors, remained unchallenged until 1829, the year Nobili invented the thermocouple. (Herschel's own thermometer could be read to 0.2 °C (0.036 °F), and later models were able to be read to 0.05 °C (0.09 °F)). Then a breakthrough occurred; Melloni connected a number of thermocouples in series to form the first thermopile. The new device was at least 40 times as sensitive as the best thermometer of the day for detecting heat radiation – capable of detecting the heat from a person standing three meters away.

The first so-called 'heat-picture' became possible in 1840, the result of work by Sir John Herschel, son of the discoverer of the infrared and a famous astronomer in his own right. Based upon the differential evaporation of a thin film of oil when exposed to a heat pattern focused upon it, the thermal image could be seen by reflected light where the interference effects of the oil film made the image visible to the eye. Sir John also managed to obtain a primitive record of the thermal image on paper, which he called a 'thermograph'.

10399003;a2

Figure 12.4 Samuel P. Langley (1834–1906)

The improvement of infrared-detector sensitivity progressed slowly. Another major breakthrough, made by Langley in 1880, was the invention of the bolometer. This consisted of a thin blackened strip of platinum connected in one arm of a Wheatstone bridge circuit upon which the infrared radiation was focused and to which a sensitive galvanometer responded. This instrument is said to have been able to detect the heat from a cow at a distance of 400 meters.

An English scientist, Sir James Dewar, first introduced the use of liquefied gases as cooling agents (such as liquid nitrogen with a temperature of -196 °C (-320.8 °F)) in low temperature research. In 1892 he invented a unique vacuum insulating container in which it is possible to store liquefied gases for entire days. The common 'thermos bottle', used for storing hot and cold drinks, is based upon his invention.

Between the years 1900 and 1920, the inventors of the world 'discovered' the infrared. Many patents were issued for devices to detect personnel, artillery, aircraft, ships – and even icebergs. The first operating systems, in the modern sense, began to be developed during the 1914–18 war, when both sides had research programs devoted to the military exploitation of the infrared. These programs included experimental systems for enemy intrusion/detection, remote temperature sensing, secure communications, and 'flying torpedo' guidance. An infrared search system tested during this period was able to detect an approaching airplane at a distance of 1.5 km (0.94 miles), or a person more than 300 meters (984 ft.) away.

The most sensitive systems up to this time were all based upon variations of the bolometer idea, but the period between the two wars saw the development of two revolutionary new infrared detectors: the image converter and the photon detector. At first, the image converter received the greatest attention by the military, because it enabled an observer for the first time in history to literally 'see in the dark'. However, the sensitivity of the image converter was limited to the near infrared wavelengths, and the most interesting military targets (i.e. enemy soldiers) had to be illuminated by infrared search beams. Since this involved the risk of giving away the observer's position to a similarly-equipped enemy observer, it is understandable that military interest in the image converter eventually faded.

The tactical military disadvantages of so-called 'active' (i.e. search beam-equipped) thermal imaging systems provided impetus following the 1939–45 war for extensive secret military infrared-research programs into the possibilities of developing 'passive' (no search beam) systems around the extremely sensitive photon detector. During this period, military secrecy regulations completely prevented disclosure of the status of infrared-imaging technology. This secrecy only began to be lifted in the middle of the 1950's, and from that time adequate thermal-imaging devices finally began to be available to civilian science and industry.

13 Theory of thermography

13.1 Introduction

The subjects of infrared radiation and the related technique of thermography are still new to many who will use an infrared camera. In this section the theory behind thermography will be given.

13.2 The electromagnetic spectrum

The electromagnetic spectrum is divided arbitrarily into a number of wavelength regions, called *bands*, distinguished by the methods used to produce and detect the radiation. There is no fundamental difference between radiation in the different bands of the electromagnetic spectrum. They are all governed by the same laws and the only differences are those due to differences in wavelength.

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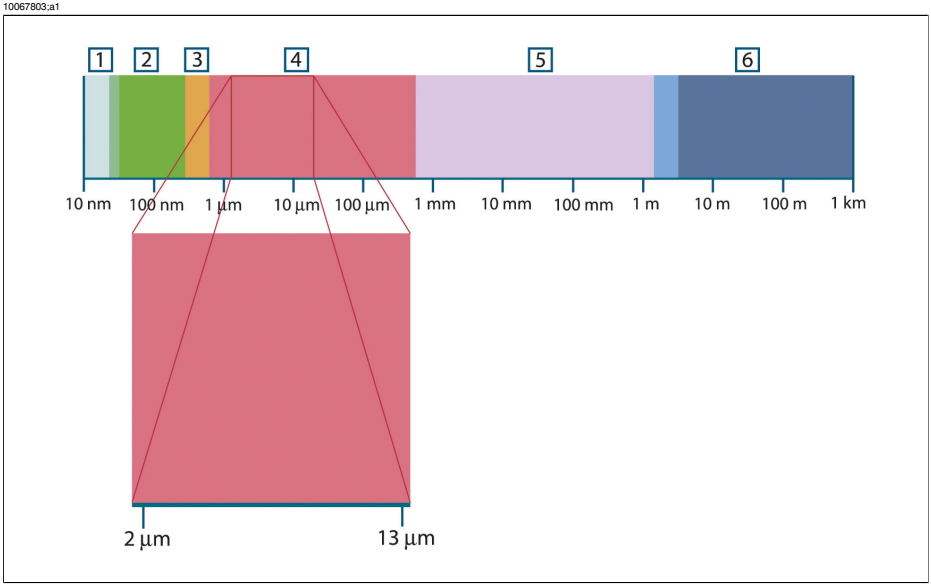

Figure 13.1 The electromagnetic spectrum. **1:** X-ray; **2:** UV; **3:** Visible; **4:** IR; **5:** Microwaves; **6:** Radiowaves.

Thermography makes use of the infrared spectral band. At the short-wavelength end the boundary lies at the limit of visual perception, in the deep red. At the long-wavelength end it merges with the microwave radio wavelengths, in the millimeter range.

The infrared band is often further subdivided into four smaller bands, the boundaries of which are also arbitrarily chosen. They include: the *near infrared* (0.75–3 µm), the *middle infrared* (3–6 µm), the *far infrared* (6–15 µm) and the *extreme infrared* (15–100

µm). Although the wavelengths are given in µm (micrometers), other units are often still used to measure wavelength in this spectral region, *e.g.* nanometer (nm) and Ångström (Å).

The relationships between the different wavelength measurements is:

$$10\ 000\ \text{Å} = 1\ 000\ \text{nm} = 1\ \mu = 1\ \mu\text{m}$$

13.3 Blackbody radiation

A blackbody is defined as an object which absorbs all radiation that impinges on it at any wavelength. The apparent misnomer *black* relating to an object emitting radiation is explained by Kirchhoff's Law (after *Gustav Robert Kirchhoff*, 1824–1887), which states that a body capable of absorbing all radiation at any wavelength is equally capable in the emission of radiation.

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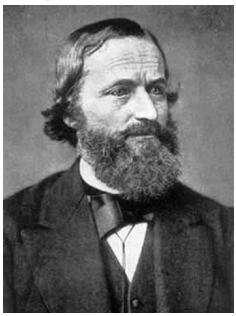

Figure 13.2 Gustav Robert Kirchhoff (1824–1887)

The construction of a blackbody source is, in principle, very simple. The radiation characteristics of an aperture in an isotherm cavity made of an opaque absorbing material represents almost exactly the properties of a blackbody. A practical application of the principle to the construction of a perfect absorber of radiation consists of a box that is light tight except for an aperture in one of the sides. Any radiation which then enters the hole is scattered and absorbed by repeated reflections so only an infinitesimal fraction can possibly escape. The blackness which is obtained at the aperture is nearly equal to a blackbody and almost perfect for all wavelengths.

By providing such an isothermal cavity with a suitable heater it becomes what is termed a *cavity radiator*. An isothermal cavity heated to a uniform temperature generates blackbody radiation, the characteristics of which are determined solely by the temperature of the cavity. Such cavity radiators are commonly used as sources of radiation in temperature reference standards in the laboratory for calibrating thermographic instruments, such as a FLIR Systems camera for example.

If the temperature of blackbody radiation increases to more than 525°C (977°F), the source begins to be visible so that it appears to the eye no longer black. This is the incipient red heat temperature of the radiator, which then becomes orange or yellow as the temperature increases further. In fact, the definition of the so-called *color temperature* of an object is the temperature to which a blackbody would have to be heated to have the same appearance.

Now consider three expressions that describe the radiation emitted from a blackbody.

13.3.1 Planck's law

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Figure 13.3 Max Planck (1858–1947)

Max Planck (1858–1947) was able to describe the spectral distribution of the radiation from a blackbody by means of the following formula:

$$W_{\lambda b} = \frac{2\pi hc^2}{\lambda^5\left(e^{hc/\lambda kT} - 1\right)} \times 10^{-6}[Watt/m^2, \mu m]$$

where:

$W_{\lambda b}$	Blackbody spectral radiant emittance at wavelength λ.
c	Velocity of light = 3×10^8 m/s
h	Planck's constant = 6.6×10^{-34} Joule sec.
k	Boltzmann's constant = 1.4×10^{-23} Joule/K.
T	Absolute temperature (K) of a blackbody.
λ	Wavelength (μm).

➲ The factor 10^{-6} is used since spectral emittance in the curves is expressed in Watt/m^2, µm.

Planck's formula, when plotted graphically for various temperatures, produces a family of curves. Following any particular Planck curve, the spectral emittance is zero at $\lambda = 0$, then increases rapidly to a maximum at a wavelength λ_{max} and after passing it approaches zero again at very long wavelengths. The higher the temperature, the shorter the wavelength at which maximum occurs.

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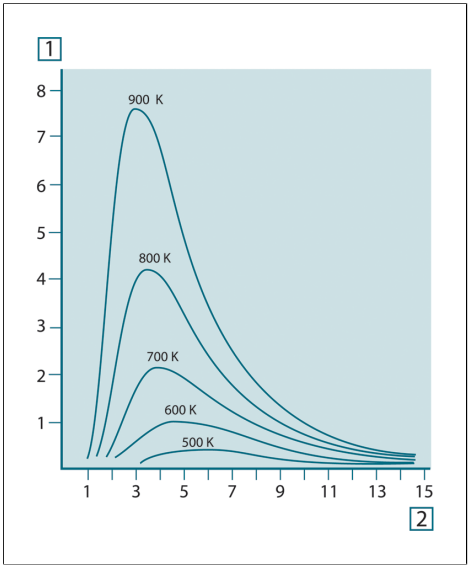

Figure 13.4 Blackbody spectral radiant emittance according to Planck's law, plotted for various absolute temperatures. **1:** Spectral radiant emittance (W/cm^2 × 10^3(µm)); **2:** Wavelength (µm)

13.3.2 Wien's displacement law

By differentiating Planck's formula with respect to λ, and finding the maximum, we have:

$$\lambda_{\max} = \frac{2898}{T}[\mu m]$$

This is Wien's formula (after *Wilhelm Wien*, 1864–1928), which expresses mathematically the common observation that colors vary from red to orange or yellow as the temperature of a thermal radiator increases. The wavelength of the color is the same as the wavelength calculated for λ_{max}. A good approximation of the value of λ_{max} for a given blackbody temperature is obtained by applying the rule-of-thumb 3 000/T

µm. Thus, a very hot star such as Sirius (11 000 K), emitting bluish-white light, radiates with the peak of spectral radiant emittance occurring within the invisible ultraviolet spectrum, at wavelength 0.27 µm.

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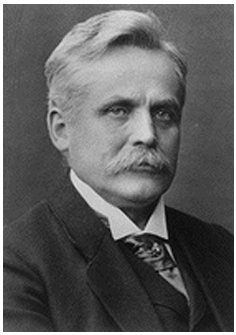

Figure 13.5 Wilhelm Wien (1864–1928)

The sun (approx. 6 000 K) emits yellow light, peaking at about 0.5 µm in the middle of the visible light spectrum.

At room temperature (300 K) the peak of radiant emittance lies at 9.7 µm, in the far infrared, while at the temperature of liquid nitrogen (77 K) the maximum of the almost insignificant amount of radiant emittance occurs at 38 µm, in the extreme infrared wavelengths.

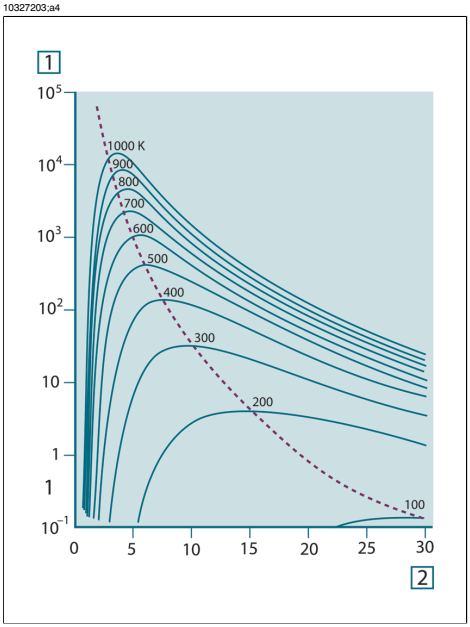

Figure 13.6 Planckian curves plotted on semi-log scales from 100 K to 1000 K. The dotted line represents the locus of maximum radiant emittance at each temperature as described by Wien's displacement law. **1:** Spectral radiant emittance (W/cm^2 (µm)); **2:** Wavelength (µm).

13.3.3 Stefan-Boltzmann's law

By integrating Planck's formula from λ = 0 to λ = ∞, we obtain the total radiant emittance (W_b) of a blackbody:

$$W_b = \sigma T^4 \ [\mathrm{Watt/m^2}]$$

This is the Stefan-Boltzmann formula (after *Josef Stefan*, 1835–1893, and *Ludwig Boltzmann*, 1844–1906), which states that the total emissive power of a blackbody is proportional to the fourth power of its absolute temperature. Graphically, W_b represents the area below the Planck curve for a particular temperature. It can be shown that the radiant emittance in the interval λ = 0 to λ_{max} is only 25% of the total, which represents about the amount of the sun's radiation which lies inside the visible light spectrum.

10399303;a1

Figure 13.7 Josef Stefan (1835–1893), and Ludwig Boltzmann (1844–1906)

Using the Stefan-Boltzmann formula to calculate the power radiated by the human body, at a temperature of 300 K and an external surface area of approx. 2 m^2, we obtain 1 kW. This power loss could not be sustained if it were not for the compensating absorption of radiation from surrounding surfaces, at room temperatures which do not vary too drastically from the temperature of the body – or, of course, the addition of clothing.

13.3.4 Non-blackbody emitters

So far, only blackbody radiators and blackbody radiation have been discussed. However, real objects almost never comply with these laws over an extended wavelength region – although they may approach the blackbody behavior in certain spectral intervals. For example, a certain type of white paint may appear perfectly *white* in the visible light spectrum, but becomes distinctly *gray* at about 2 µm, and beyond 3 µm it is almost *black*.

There are three processes which can occur that prevent a real object from acting like a blackbody: a fraction of the incident radiation α may be absorbed, a fraction ρ may be reflected, and a fraction τ may be transmitted. Since all of these factors are more or less wavelength dependent, the subscript λ is used to imply the spectral dependence of their definitions. Thus:

- The spectral absorptance α_λ = the ratio of the spectral radiant power absorbed by an object to that incident upon it.
- The spectral reflectance ρ_λ = the ratio of the spectral radiant power reflected by an object to that incident upon it.
- The spectral transmittance τ_λ = the ratio of the spectral radiant power transmitted through an object to that incident upon it.

The sum of these three factors must always add up to the whole at any wavelength, so we have the relation:

$$\alpha_\lambda + \rho_\lambda + \tau_\lambda = 1$$

For opaque materials $\tau_\lambda = 0$ and the relation simplifies to:

$$\alpha_\lambda + \rho_\lambda = 1$$

Another factor, called the emissivity, is required to describe the fraction ε of the radiant emittance of a blackbody produced by an object at a specific temperature. Thus, we have the definition:

The spectral emissivity ε_λ= the ratio of the spectral radiant power from an object to that from a blackbody at the same temperature and wavelength.

Expressed mathematically, this can be written as the ratio of the spectral emittance of the object to that of a blackbody as follows:

$$\varepsilon_\lambda = \frac{W_{\lambda o}}{W_{\lambda b}}$$

Generally speaking, there are three types of radiation source, distinguished by the ways in which the spectral emittance of each varies with wavelength.

- A blackbody, for which $\varepsilon_\lambda = \varepsilon = 1$
- A graybody, for which $\varepsilon_\lambda = \varepsilon$ = constant less than 1
- A selective radiator, for which ε varies with wavelength

According to Kirchhoff's law, for any material the spectral emissivity and spectral absorptance of a body are equal at any specified temperature and wavelength. That is:

$$\varepsilon_\lambda = \alpha_\lambda$$

From this we obtain, for an opaque material (since $\alpha_\lambda + \rho_\lambda = 1$):

$$\varepsilon_\lambda + \rho_\lambda = 1$$

For highly polished materials ε_λ approaches zero, so that for a perfectly reflecting material (*i.e.* a perfect mirror) we have:

$$\rho_\lambda = 1$$

For a graybody radiator, the Stefan-Boltzmann formula becomes:

$$W = \varepsilon \sigma T^4 \, [\mathrm{Watt/m^2}]$$

This states that the total emissive power of a graybody is the same as a blackbody at the same temperature reduced in proportion to the value of ε from the graybody.

10401203;a2

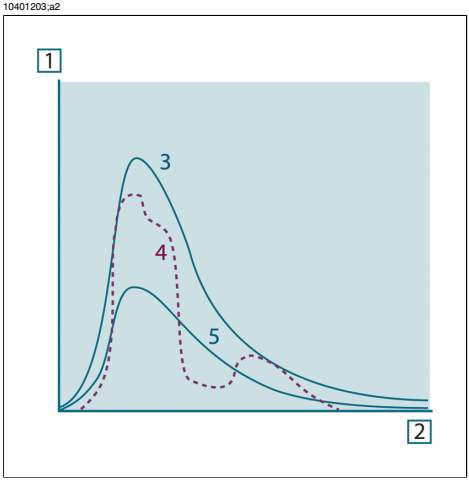

Figure 13.8 Spectral radiant emittance of three types of radiators. **1:** Spectral radiant emittance; **2:** Wavelength; **3:** Blackbody; **4:** Selective radiator; **5:** Graybody.

10327303;a4

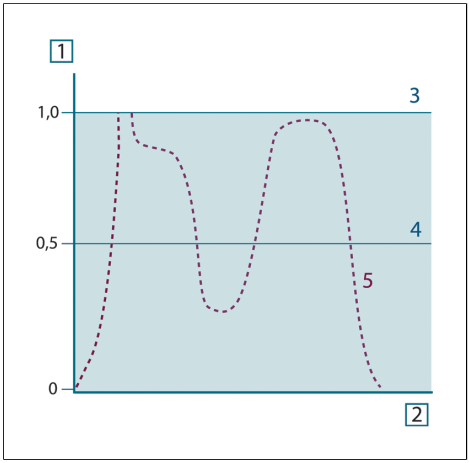

Figure 13.9 Spectral emissivity of three types of radiators. **1:** Spectral emissivity; **2:** Wavelength; **3:** Blackbody; **4:** Graybody; **5:** Selective radiator.

13.4 Infrared semi-transparent materials

Consider now a non-metallic, semi-transparent body – let us say, in the form of a thick flat plate of plastic material. When the plate is heated, radiation generated within its volume must work its way toward the surfaces through the material in which it is partially absorbed. Moreover, when it arrives at the surface, some of it is reflected back into the interior. The back-reflected radiation is again partially absorbed, but

some of it arrives at the other surface, through which most of it escapes; part of it is reflected back again. Although the progressive reflections become weaker and weaker they must all be added up when the total emittance of the plate is sought. When the resulting geometrical series is summed, the effective emissivity of a semi-transparent plate is obtained as:

$$\varepsilon_\lambda = \frac{(1-\rho_\lambda)(1-\tau_\lambda)}{1-\rho_\lambda\tau_\lambda}$$

When the plate becomes opaque this formula is reduced to the single formula:

$$\varepsilon_\lambda = 1-\rho_\lambda$$

This last relation is a particularly convenient one, because it is often easier to measure reflectance than to measure emissivity directly.

14 The measurement formula

As already mentioned, when viewing an object, the camera receives radiation not only from the object itself. It also collects radiation from the surroundings reflected via the object surface. Both these radiation contributions become attenuated to some extent by the atmosphere in the measurement path. To this comes a third radiation contribution from the atmosphere itself.

This description of the measurement situation, as illustrated in the figure below, is so far a fairly true description of the real conditions. What has been neglected could for instance be sun light scattering in the atmosphere or stray radiation from intense radiation sources outside the field of view. Such disturbances are difficult to quantify, however, in most cases they are fortunately small enough to be neglected. In case they are not negligible, the measurement configuration is likely to be such that the risk for disturbance is obvious, at least to a trained operator. It is then his responsibility to modify the measurement situation to avoid the disturbance e.g. by changing the viewing direction, shielding off intense radiation sources etc.

Accepting the description above, we can use the figure below to derive a formula for the calculation of the object temperature from the calibrated camera output.

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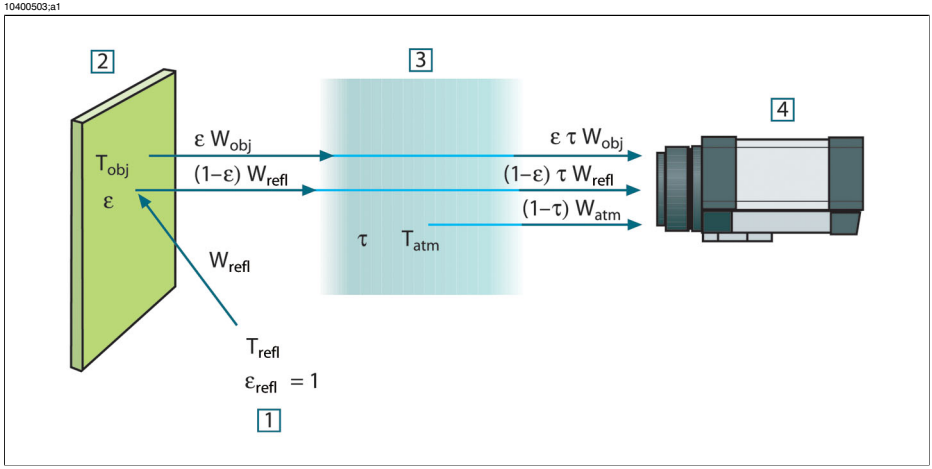

Figure 14.1 A schematic representation of the general thermographic measurement situation.**1:** Surroundings; **2:** Object; **3:** Atmosphere; **4:** Camera

Assume that the received radiation power W from a blackbody source of temperature T_{source} on short distance generates a camera output signal U_{source} that is proportional to the power input (power linear camera). We can then write (Equation 1):

$$U_{source} = CW(T_{source})$$

or, with simplified notation:

$$U_{source} = CW_{source}$$

where C is a constant.

Should the source be a graybody with emittance ε, the received radiation would consequently be εW_{source}.

We are now ready to write the three collected radiation power terms:

1 – Emission from the object = $\varepsilon\tau W_{obj}$, where ε is the emittance of the object and τ is the transmittance of the atmosphere. The object temperature is T_{obj}.

2 – Reflected emission from ambient sources = $(1 - \varepsilon)\tau W_{refl}$, where (1 – ε) is the reflectance of the object. The ambient sources have the temperature T_{refl}.

It has here been assumed that the temperature T_{refl} is the same for all emitting surfaces within the halfsphere seen from a point on the object surface. This is of course sometimes a simplification of the true situation. It is, however, a necessary simplification in order to derive a workable formula, and T_{refl} can – at least theoretically – be given a value that represents an efficient temperature of a complex surrounding.

Note also that we have assumed that the emittance for the surroundings = 1. This is correct in accordance with Kirchhoff's law: All radiation impinging on the surrounding surfaces will eventually be absorbed by the same surfaces. Thus the emittance = 1. (Note though that the latest discussion requires the complete sphere around the object to be considered.)

3 – Emission from the atmosphere = $(1 - \tau)\tau W_{atm}$, where (1 – τ) is the emittance of the atmosphere. The temperature of the atmosphere is T_{atm}.

The total received radiation power can now be written (Equation 2):

$$W_{tot} = \varepsilon\tau W_{obj} + (1 - \varepsilon)\tau W_{refl} + (1 - \tau)W_{atm}$$

We multiply each term by the constant C of Equation 1 and replace the CW products by the corresponding U according to the same equation, and get (Equation 3):

$$U_{tot} = \varepsilon\tau U_{obj} + (1 - \varepsilon)\tau U_{refl} + (1 - \tau)U_{atm}$$

14

Solve Equation 3 for U_{obj} (Equation 4):

$$U_{obj} = \frac{1}{\varepsilon\tau}U_{tot} - \frac{1-\varepsilon}{\varepsilon}U_{refl} - \frac{1-\tau}{\varepsilon\tau}U_{atm}$$

This is the general measurement formula used in all the FLIR Systems thermographic equipment. The voltages of the formula are:

Figure 14.2 Voltages

U_{obj}	Calculated camera output voltage for a blackbody of temperature T_{obj} i.e. a voltage that can be directly converted into true requested object temperature.
U_{tot}	Measured camera output voltage for the actual case.
U_{refl}	Theoretical camera output voltage for a blackbody of temperature T_{refl} according to the calibration.
U_{atm}	Theoretical camera output voltage for a blackbody of temperature T_{atm} according to the calibration.

The operator has to supply a number of parameter values for the calculation:

- the object emittance ε,
- the relative humidity,
- T_{atm}
- object distance (D_{obj})
- the (effective) temperature of the object surroundings, or the reflected ambient temperature T_{refl}, and
- the temperature of the atmosphere T_{atm}

This task could sometimes be a heavy burden for the operator since there are normally no easy ways to find accurate values of emittance and atmospheric transmittance for the actual case. The two temperatures are normally less of a problem provided the surroundings do not contain large and intense radiation sources.

A natural question in this connection is: How important is it to know the right values of these parameters? It could though be of interest to get a feeling for this problem already here by looking into some different measurement cases and compare the relative magnitudes of the three radiation terms. This will give indications about when it is important to use correct values of which parameters.

The figures below illustrates the relative magnitudes of the three radiation contributions for three different object temperatures, two emittances, and two spectral ranges: SW and LW. Remaining parameters have the following fixed values:

- $\tau = 0.88$
- T_{refl} = +20°C (+68°F)
- T_{atm} = +20°C (+68°F)

It is obvious that measurement of low object temperatures are more critical than measuring high temperatures since the 'disturbing' radiation sources are relatively much stronger in the first case. Should also the object emittance be low, the situation would be still more difficult.

We have finally to answer a question about the importance of being allowed to use the calibration curve above the highest calibration point, what we call extrapolation. Imagine that we in a certain case measure U_{tot} = 4.5 volts. The highest calibration point for the camera was in the order of 4.1 volts, a value unknown to the operator. Thus, even if the object happened to be a blackbody, i.e. $U_{obj} = U_{tot}$, we are actually performing extrapolation of the calibration curve when converting 4.5 volts into temperature.

Let us now assume that the object is not black, it has an emittance of 0.75, and the transmittance is 0.92. We also assume that the two second terms of Equation 4 amount to 0.5 volts together. Computation of U_{obj} by means of Equation 4 then results in U_{obj} = 4.5 / 0.75 / 0.92 – 0.5 = 6.0. This is a rather extreme extrapolation, particularly when considering that the video amplifier might limit the output to 5 volts! Note, though, that the application of the calibration curve is a theoretical procedure where no electronic or other limitations exist. We trust that if there had been no signal limitations in the camera, and if it had been calibrated far beyond 5 volts, the resulting curve would have been very much the same as our real curve extrapolated beyond 4.1 volts, provided the calibration algorithm is based on radiation physics, like the FLIR Systems algorithm. Of course there must be a limit to such extrapolations.

10400603;a2

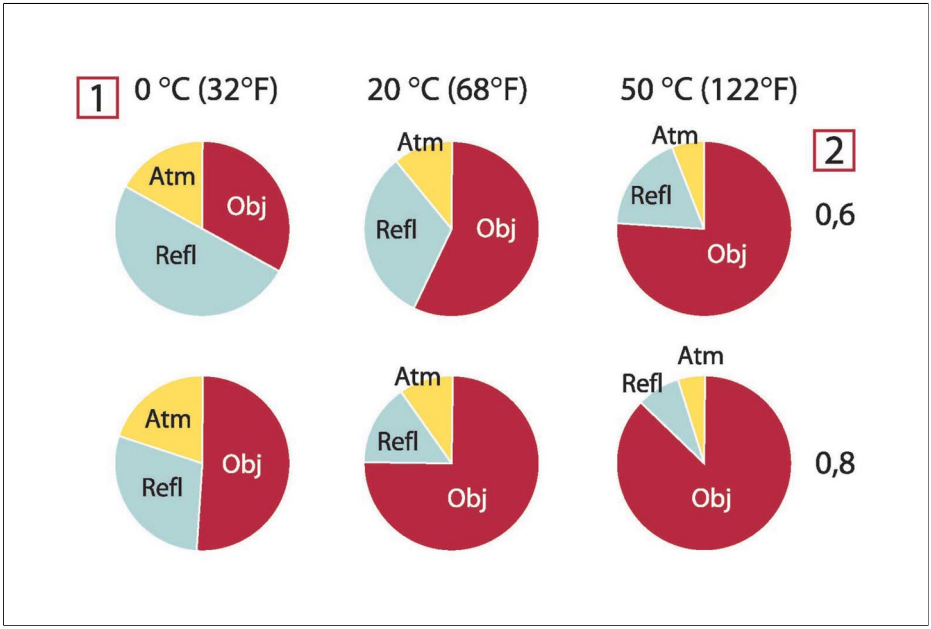

Figure 14.3 Relative magnitudes of radiation sources under varying measurement conditions (SW camera). **1:** Object temperature; **2:** Emittance; **Obj:** Object radiation; **Refl:** Reflected radiation; **Atm:** atmosphere radiation. Fixed parameters: $\tau = 0.88$; $T_{refl} = 20°C$ (+68°F); $T_{atm} = 20°C$ (+68°F).

10400703;a2

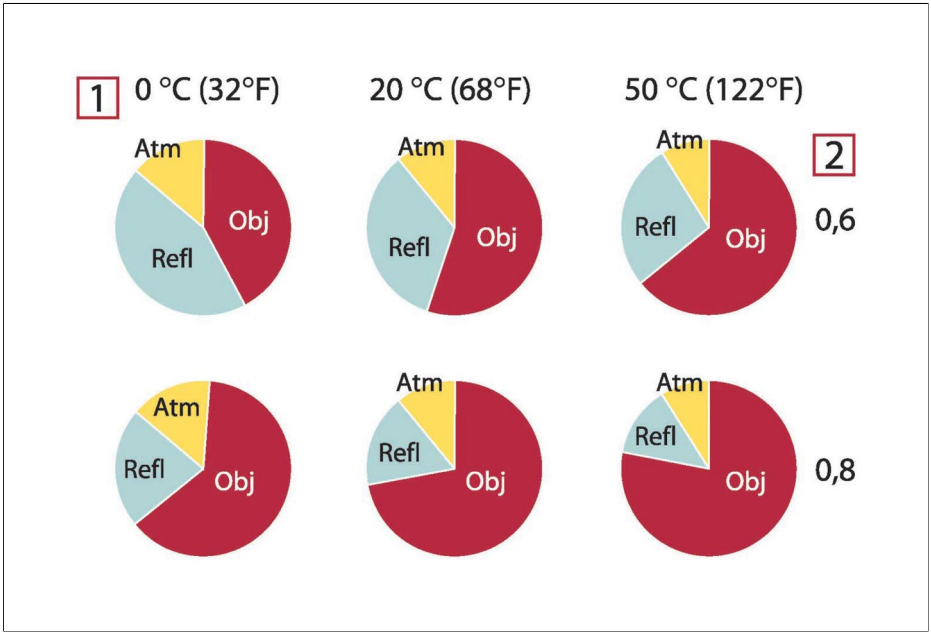

Figure 14.4 Relative magnitudes of radiation sources under varying measurement conditions (LW camera). **1:** Object temperature; **2:** Emittance; **Obj:** Object radiation; **Refl:** Reflected radiation; **Atm:** atmosphere radiation. Fixed parameters: $\tau = 0.88$; $T_{refl} = 20°C$ (+68°F); $T_{atm} = 20°C$ (+68°F).

15 Emissivity tables

This section presents a compilation of emissivity data from the infrared literature and measurements made by FLIR Systems.

15.1 References

1	Mikaél A. Bramson: *Infrared Radiation, A Handbook for Applications*, Plenum press, N.Y.
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3	Madding, R. P.: *Thermographic Instruments and systems*. Madison, Wisconsin: University of Wisconsin – Extension, Department of Engineering and Applied Science.
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7	Vlcek, J: *Determination of emissivity with imaging radiometers and some emissivities at $\lambda = 5$ µm.* Photogrammetric Engineering and Remote Sensing.
8	Kern: *Evaluation of infrared emission of clouds and ground as measured by weather satellites*, Defence Documentation Center, AD 617 417.
9	Öhman, Claes: *Emittansmätningar med AGEMA E-Box*. Teknisk rapport, AGEMA 1999. (Emittance measurements using AGEMA E-Box. Technical report, AGEMA 1999.)
10	Matteï, S., Tang-Kwor, E: *Emissivity measurements for Nextel Velvet coating 811-21 between –36°C AND 82°C.*
11	Lohrengel & Todtenhaupt (1996)
12	ITC Technical publication 32.
13	ITC Technical publication 29.

15.2 Important note about the emissivity tables

The type of camera that has been used when compiling the emissivity data is specified in column 4. The values should be regarded as recommendations only and used with caution.

15.3 Tables

Figure 15.1 1: Material; **2:** Specification; **3:** Temperature in °C; **4:** Spectrum (**T:** Total spectrum; **SW:** 2–5 μm; **LW:** 8–14 μm, **LLW:** 6.5–20 μm); **5:** Emissivity: **6:** Reference to literature source above

1	2	3	4	5	6
3M type 35	Vinyl electrical tape (several colors)	< 80	LW	Ca. 0.96	13
3M type 88	Black vinyl electrical tape	< 105	LW	Ca. 0.96	13
3M type 88	Black vinyl electrical tape	< 105	MW	< 0.96	13
3M type Super 33+	Black vinyl electrical tape	< 80	LW	Ca. 0.96	13
Aluminum	anodized, black, dull	70	LW	0.95	9
Aluminum	anodized, black, dull	70	SW	0.67	9
Aluminum	anodized, light gray, dull	70	LW	0.97	9
Aluminum	anodized, light gray, dull	70	SW	0.61	9
Aluminum	anodized sheet	100	T	0.55	2
Aluminum	as received, plate	100	T	0.09	4
Aluminum	as received, sheet	100	T	0.09	2
Aluminum	cast, blast cleaned	70	LW	0.46	9
Aluminum	cast, blast cleaned	70	SW	0.47	9
Aluminum	dipped in HNO_3, plate	100	T	0.05	4
Aluminum	foil	27	3 μm	0.09	3
Aluminum	foil	27	10 μm	0.04	3
Aluminum	oxidized, strongly	50–500	T	0.2–0.3	1
Aluminum	polished	50–100	T	0.04–0.06	1
Aluminum	polished, sheet	100	T	0.05	2
Aluminum	polished plate	100	T	0.05	4

1	2	3	4	5	6
Aluminum	roughened	27	3 μm	0.28	3
Aluminum	roughened	27	10 μm	0.18	3
Aluminum	rough surface	20–50	T	0.06–0.07	1
Aluminum	sheet, 4 samples differently scratched	70	LW	0.03–0.06	9
Aluminum	sheet, 4 samples differently scratched	70	SW	0.05–0.08	9
Aluminum	vacuum deposited	20	T	0.04	2
Aluminum	weathered, heavily	17	SW	0.83–0.94	5
Aluminum bronze		20	T	0.60	1
Aluminum hydroxide	powder		T	0.28	1
Aluminum oxide	activated, powder		T	0.46	1
Aluminum oxide	pure, powder (alumina)		T	0.16	1
Asbestos	board	20	T	0.96	1
Asbestos	fabric		T	0.78	1
Asbestos	floor tile	35	SW	0.94	7
Asbestos	paper	40–400	T	0.93–0.95	1
Asbestos	powder		T	0.40–0.60	1
Asbestos	slate	20	T	0.96	1
Asphalt paving		4	LLW	0.967	8
Brass	dull, tarnished	20–350	T	0.22	1
Brass	oxidized	70	SW	0.04–0.09	9
Brass	oxidized	70	LW	0.03–0.07	9
Brass	oxidized	100	T	0.61	2
Brass	oxidized at 600°C	200–600	T	0.59–0.61	1
Brass	polished	200	T	0.03	1
Brass	polished, highly	100	T	0.03	2

1	2	3	4	5	6
Brass	rubbed with 80-grit emery	20	T	0.20	2
Brass	sheet, rolled	20	T	0.06	1
Brass	sheet, worked with emery	20	T	0.2	1
Brick	alumina	17	SW	0.68	5
Brick	common	17	SW	0.86–0.81	5
Brick	Dinas silica, glazed, rough	1100	T	0.85	1
Brick	Dinas silica, refractory	1000	T	0.66	1
Brick	Dinas silica, unglazed, rough	1000	T	0.80	1
Brick	firebrick	17	SW	0.68	5
Brick	fireclay	20	T	0.85	1
Brick	fireclay	1000	T	0.75	1
Brick	fireclay	1200	T	0.59	1
Brick	masonry	35	SW	0.94	7
Brick	masonry, plastered	20	T	0.94	1
Brick	red, common	20	T	0.93	2
Brick	red, rough	20	T	0.88–0.93	1
Brick	refractory, corundum	1000	T	0.46	1
Brick	refractory, magnesite	1000–1300	T	0.38	1
Brick	refractory, strongly radiating	500–1000	T	0.8–0.9	1
Brick	refractory, weakly radiating	500–1000	T	0.65–0.75	1
Brick	silica, 95% SiO_2	1230	T	0.66	1
Brick	sillimanite, 33% SiO_2, 64% Al_2O_3	1500	T	0.29	1

1	2	3	4	5	6
Brick	waterproof	17	SW	0.87	5
Bronze	phosphor bronze	70	LW	0.06	9
Bronze	phosphor bronze	70	SW	0.08	9
Bronze	polished	50	T	0.1	1
Bronze	porous, rough	50–150	T	0.55	1
Bronze	powder		T	0.76–0.80	1
Carbon	candle soot	20	T	0.95	2
Carbon	charcoal powder		T	0.96	1
Carbon	graphite, filed surface	20	T	0.98	2
Carbon	graphite powder		T	0.97	1
Carbon	lampblack	20–400	T	0.95–0.97	1
Chipboard	untreated	20	SW	0.90	6
Chromium	polished	50	T	0.10	1
Chromium	polished	500–1000	T	0.28–0.38	1
Clay	fired	70	T	0.91	1
Cloth	black	20	T	0.98	1
Concrete		20	T	0.92	2
Concrete	dry	36	SW	0.95	7
Concrete	rough	17	SW	0.97	5
Concrete	walkway	5	LLW	0.974	8
Copper	commercial, burnished	20	T	0.07	1
Copper	electrolytic, carefully polished	80	T	0.018	1
Copper	electrolytic, polished	–34	T	0.006	4
Copper	molten	1100–1300	T	0.13–0.15	1
Copper	oxidized	50	T	0.6–0.7	1
Copper	oxidized, black	27	T	0.78	4

1	2	3	4	5	6
Copper	oxidized, heavily	20	T	0.78	2
Copper	oxidized to blackness		T	0.88	1
Copper	polished	50–100	T	0.02	1
Copper	polished	100	T	0.03	2
Copper	polished, commercial	27	T	0.03	4
Copper	polished, mechanical	22	T	0.015	4
Copper	pure, carefully prepared surface	22	T	0.008	4
Copper	scraped	27	T	0.07	4
Copper dioxide	powder		T	0.84	1
Copper oxide	red, powder		T	0.70	1
Ebonite			T	0.89	1
Emery	coarse	80	T	0.85	1
Enamel		20	T	0.9	1
Enamel	lacquer	20	T	0.85–0.95	1
Fiber board	hard, untreated	20	SW	0.85	6
Fiber board	masonite	70	LW	0.88	9
Fiber board	masonite	70	SW	0.75	9
Fiber board	particle board	70	LW	0.89	9
Fiber board	particle board	70	SW	0.77	9
Fiber board	porous, untreated	20	SW	0.85	6
Gold	polished	130	T	0.018	1
Gold	polished, carefully	200–600	T	0.02–0.03	1
Gold	polished, highly	100	T	0.02	2
Granite	polished	20	LLW	0.849	8
Granite	rough	21	LLW	0.879	8
Granite	rough, 4 different samples	70	LW	0.77–0.87	9

1	2	3	4	5	6
Granite	rough, 4 different samples	70	SW	0.95–0.97	9
Gypsum		20	T	0.8–0.9	1
Ice: See Water					
Iron, cast	casting	50	T	0.81	1
Iron, cast	ingots	1000	T	0.95	1
Iron, cast	liquid	1300	T	0.28	1
Iron, cast	machined	800–1000	T	0.60–0.70	1
Iron, cast	oxidized	38	T	0.63	4
Iron, cast	oxidized	100	T	0.64	2
Iron, cast	oxidized	260	T	0.66	4
Iron, cast	oxidized	538	T	0.76	4
Iron, cast	oxidized at 600°C	200–600	T	0.64–0.78	1
Iron, cast	polished	38	T	0.21	4
Iron, cast	polished	40	T	0.21	2
Iron, cast	polished	200	T	0.21	1
Iron, cast	unworked	900–1100	T	0.87–0.95	1
Iron and steel	cold rolled	70	LW	0.09	9
Iron and steel	cold rolled	70	SW	0.20	9
Iron and steel	covered with red rust	20	T	0.61–0.85	1
Iron and steel	electrolytic	22	T	0.05	4
Iron and steel	electrolytic	100	T	0.05	4
Iron and steel	electrolytic	260	T	0.07	4
Iron and steel	electrolytic, carefully polished	175–225	T	0.05–0.06	1
Iron and steel	freshly worked with emery	20	T	0.24	1
Iron and steel	ground sheet	950–1100	T	0.55–0.61	1
Iron and steel	heavily rusted sheet	20	T	0.69	2

1	2	3	4	5	6
Iron and steel	hot rolled	20	T	0.77	1
Iron and steel	hot rolled	130	T	0.60	1
Iron and steel	oxidized	100	T	0.74	1
Iron and steel	oxidized	100	T	0.74	4
Iron and steel	oxidized	125–525	T	0.78–0.82	1
Iron and steel	oxidized	200	T	0.79	2
Iron and steel	oxidized	1227	T	0.89	4
Iron and steel	oxidized	200–600	T	0.80	1
Iron and steel	oxidized strongly	50	T	0.88	1
Iron and steel	oxidized strongly	500	T	0.98	1
Iron and steel	polished	100	T	0.07	2
Iron and steel	polished	400–1000	T	0.14–0.38	1
Iron and steel	polished sheet	750–1050	T	0.52–0.56	1
Iron and steel	rolled, freshly	20	T	0.24	1
Iron and steel	rolled sheet	50	T	0.56	1
Iron and steel	rough, plane surface	50	T	0.95–0.98	1
Iron and steel	rusted, heavily	17	SW	0.96	5
Iron and steel	rusted red, sheet	22	T	0.69	4
Iron and steel	rusty, red	20	T	0.69	1
Iron and steel	shiny, etched	150	T	0.16	1
Iron and steel	shiny oxide layer, sheet,	20	T	0.82	1
Iron and steel	wrought, carefully polished	40–250	T	0.28	1
Iron galvanized	heavily oxidized	70	LW	0.85	9
Iron galvanized	heavily oxidized	70	SW	0.64	9
Iron galvanized	sheet	92	T	0.07	4
Iron galvanized	sheet, burnished	30	T	0.23	1
Iron galvanized	sheet, oxidized	20	T	0.28	1

1	2	3	4	5	6
Iron tinned	sheet	24	T	0.064	4
Krylon Ultra-flat black 1602	Flat black	Room temperature up to 175	LW	Ca. 0.96	12
Krylon Ultra-flat black 1602	Flat black	Room temperature up to 175	MW	Ca. 0.97	12
Lacquer	3 colors sprayed on Aluminum	70	LW	0.92–0.94	9
Lacquer	3 colors sprayed on Aluminum	70	SW	0.50–0.53	9
Lacquer	Aluminum on rough surface	20	T	0.4	1
Lacquer	bakelite	80	T	0.83	1
Lacquer	black, dull	40–100	T	0.96–0.98	1
Lacquer	black, matte	100	T	0.97	2
Lacquer	black, shiny, sprayed on iron	20	T	0.87	1
Lacquer	heat–resistant	100	T	0.92	1
Lacquer	white	40–100	T	0.8–0.95	1
Lacquer	white	100	T	0.92	2
Lead	oxidized, gray	20	T	0.28	1
Lead	oxidized, gray	22	T	0.28	4
Lead	oxidized at 200°C	200	T	0.63	1
Lead	shiny	250	T	0.08	1
Lead	unoxidized, polished	100	T	0.05	4
Lead red		100	T	0.93	4
Lead red, powder		100	T	0.93	1
Leather	tanned		T	0.75–0.80	1
Lime			T	0.3–0.4	1
Magnesium		22	T	0.07	4
Magnesium		260	T	0.13	4

1	2	3	4	5	6
Magnesium		538	T	0.18	4
Magnesium	polished	20	T	0.07	2
Magnesium powder			T	0.86	1
Molybdenum		600–1000	T	0.08–0.13	1
Molybdenum		1500–2200	T	0.19–0.26	1
Molybdenum	filament	700–2500	T	0.1–0.3	1
Mortar		17	SW	0.87	5
Mortar	dry	36	SW	0.94	7
Nextel Velvet 811-21 Black	Flat black	–60–150	LW	> 0.97	10 and 11
Nichrome	rolled	700	T	0.25	1
Nichrome	sandblasted	700	T	0.70	1
Nichrome	wire, clean	50	T	0.65	1
Nichrome	wire, clean	500–1000	T	0.71–0.79	1
Nichrome	wire, oxidized	50–500	T	0.95–0.98	1
Nickel	bright matte	122	T	0.041	4
Nickel	commercially pure, polished	100	T	0.045	1
Nickel	commercially pure, polished	200–400	T	0.07–0.09	1
Nickel	electrolytic	22	T	0.04	4
Nickel	electrolytic	38	T	0.06	4
Nickel	electrolytic	260	T	0.07	4
Nickel	electrolytic	538	T	0.10	4
Nickel	electroplated, polished	20	T	0.05	2
Nickel	electroplated on iron, polished	22	T	0.045	4
Nickel	electroplated on iron, unpolished	20	T	0.11–0.40	1

1	2	3	4	5	6
Nickel	electroplated on iron, unpolished	22	T	0.11	4
Nickel	oxidized	200	T	0.37	2
Nickel	oxidized	227	T	0.37	4
Nickel	oxidized	1227	T	0.85	4
Nickel	oxidized at 600°C	200–600	T	0.37–0.48	1
Nickel	polished	122	T	0.045	4
Nickel	wire	200–1000	T	0.1–0.2	1
Nickel oxide		500–650	T	0.52–0.59	1
Nickel oxide		1000–1250	T	0.75–0.86	1
Oil, lubricating	0.025 mm film	20	T	0.27	2
Oil, lubricating	0.050 mm film	20	T	0.46	2
Oil, lubricating	0.125 mm film	20	T	0.72	2
Oil, lubricating	film on Ni base: Ni base only	20	T	0.05	2
Oil, lubricating	thick coating	20	T	0.82	2
Paint	8 different colors and qualities	70	LW	0.92–0.94	9
Paint	8 different colors and qualities	70	SW	0.88–0.96	9
Paint	Aluminum, various ages	50–100	T	0.27–0.67	1
Paint	cadmium yellow		T	0.28–0.33	1
Paint	chrome green		T	0.65–0.70	1
Paint	cobalt blue		T	0.7–0.8	1
Paint	oil	17	SW	0.87	5
Paint	oil, black flat	20	SW	0.94	6
Paint	oil, black gloss	20	SW	0.92	6
Paint	oil, gray flat	20	SW	0.97	6
Paint	oil, gray gloss	20	SW	0.96	6
Paint	oil, various colors	100	T	0.92–0.96	1

1	2	3	4	5	6
Paint	oil based, average of 16 colors	100	T	0.94	2
Paint	plastic, black	20	SW	0.95	6
Paint	plastic, white	20	SW	0.84	6
Paper	4 different colors	70	LW	0.92–0.94	9
Paper	4 different colors	70	SW	0.68–0.74	9
Paper	black		T	0.90	1
Paper	black, dull		T	0.94	1
Paper	black, dull	70	LW	0.89	9
Paper	black, dull	70	SW	0.86	9
Paper	blue, dark		T	0.84	1
Paper	coated with black lacquer		T	0.93	1
Paper	green		T	0.85	1
Paper	red		T	0.76	1
Paper	white	20	T	0.7–0.9	1
Paper	white, 3 different glosses	70	LW	0.88–0.90	9
Paper	white, 3 different glosses	70	SW	0.76–0.78	9
Paper	white bond	20	T	0.93	2
Paper	yellow		T	0.72	1
Plaster		17	SW	0.86	5
Plaster	plasterboard, untreated	20	SW	0.90	6
Plaster	rough coat	20	T	0.91	2
Plastic	glass fibre laminate (printed circ. board)	70	LW	0.91	9
Plastic	glass fibre laminate (printed circ. board)	70	SW	0.94	9

1	2	3	4	5	6
Plastic	polyurethane isolation board	70	LW	0.55	9
Plastic	polyurethane isolation board	70	SW	0.29	9
Plastic	PVC, plastic floor, dull, structured	70	LW	0.93	9
Plastic	PVC, plastic floor, dull, structured	70	SW	0.94	9
Platinum		17	T	0.016	4
Platinum		22	T	0.03	4
Platinum		100	T	0.05	4
Platinum		260	T	0.06	4
Platinum		538	T	0.10	4
Platinum		1000–1500	T	0.14–0.18	1
Platinum		1094	T	0.18	4
Platinum	pure, polished	200–600	T	0.05–0.10	1
Platinum	ribbon	900–1100	T	0.12–0.17	1
Platinum	wire	50–200	T	0.06–0.07	1
Platinum	wire	500–1000	T	0.10–0.16	1
Platinum	wire	1400	T	0.18	1
Porcelain	glazed	20	T	0.92	1
Porcelain	white, shiny		T	0.70–0.75	1
Rubber	hard	20	T	0.95	1
Rubber	soft, gray, rough	20	T	0.95	1
Sand			T	0.60	1
Sand		20	T	0.90	2
Sandstone	polished	19	LLW	0.909	8
Sandstone	rough	19	LLW	0.935	8
Silver	polished	100	T	0.03	2
Silver	pure, polished	200–600	T	0.02–0.03	1

1	2	3	4	5	6
Skin	human	32	T	0.98	2
Slag	boiler	0–100	T	0.97–0.93	1
Slag	boiler	200–500	T	0.89–0.78	1
Slag	boiler	600–1200	T	0.76–0.70	1
Slag	boiler	1400–1800	T	0.69–0.67	1
Snow: See Water					
Soil	dry	20	T	0.92	2
Soil	saturated with water	20	T	0.95	2
Stainless steel	alloy, 8% Ni, 18% Cr	500	T	0.35	1
Stainless steel	rolled	700	T	0.45	1
Stainless steel	sandblasted	700	T	0.70	1
Stainless steel	sheet, polished	70	LW	0.14	9
Stainless steel	sheet, polished	70	SW	0.18	9
Stainless steel	sheet, untreated, somewhat scratched	70	LW	0.28	9
Stainless steel	sheet, untreated, somewhat scratched	70	SW	0.30	9
Stainless steel	type 18-8, buffed	20	T	0.16	2
Stainless steel	type 18-8, oxidized at 800°C	60	T	0.85	2
Stucco	rough, lime	10–90	T	0.91	1
Styrofoam	insulation	37	SW	0.60	7
Tar			T	0.79–0.84	1
Tar	paper	20	T	0.91–0.93	1
Tile	glazed	17	SW	0.94	5
Tin	burnished	20–50	T	0.04–0.06	1
Tin	tin–plated sheet iron	100	T	0.07	2

1	2	3	4	5	6
Titanium	oxidized at 540°C	200	T	0.40	1
Titanium	oxidized at 540°C	500	T	0.50	1
Titanium	oxidized at 540°C	1000	T	0.60	1
Titanium	polished	200	T	0.15	1
Titanium	polished	500	T	0.20	1
Titanium	polished	1000	T	0.36	1
Tungsten		200	T	0.05	1
Tungsten		600–1000	T	0.1–0.16	1
Tungsten		1500–2200	T	0.24–0.31	1
Tungsten	filament	3300	T	0.39	1
Varnish	flat	20	SW	0.93	6
Varnish	on oak parquet floor	70	LW	0.90–0.93	9
Varnish	on oak parquet floor	70	SW	0.90	9
Wallpaper	slight pattern, light gray	20	SW	0.85	6
Wallpaper	slight pattern, red	20	SW	0.90	6
Water	distilled	20	T	0.96	2
Water	frost crystals	–10	T	0.98	2
Water	ice, covered with heavy frost	0	T	0.98	1
Water	ice, smooth	–10	T	0.96	2
Water	ice, smooth	0	T	0.97	1
Water	layer >0.1 mm thick	0–100	T	0.95–0.98	1
Water	snow		T	0.8	1
Water	snow	–10	T	0.85	2
Wood		17	SW	0.98	5
Wood		19	LLW	0.962	8
Wood	ground		T	0.5–0.7	1

1	2	3	4	5	6
Wood	pine, 4 different samples	70	LW	0.81–0.89	9
Wood	pine, 4 different samples	70	SW	0.67–0.75	9
Wood	planed	20	T	0.8–0.9	1
Wood	planed oak	20	T	0.90	2
Wood	planed oak	70	LW	0.88	9
Wood	planed oak	70	SW	0.77	9
Wood	plywood, smooth, dry	36	SW	0.82	7
Wood	plywood, untreated	20	SW	0.83	6
Wood	white, damp	20	T	0.7–0.8	1
Zinc	oxidized at 400°C	400	T	0.11	1
Zinc	oxidized surface	1000–1200	T	0.50–0.60	1
Zinc	polished	200–300	T	0.04–0.05	1
Zinc	sheet	50	T	0.20	1

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A note on the technical production of this publication

This publication was produced using XML—the *eXtensible Markup Language*. For more information about XML, please visit http://www.w3.org/XML/

A note on the typeface used in this publication

This publication was typeset using Swiss 721, which is Bitstream's pan-European version of the Helvetica™ typeface. Helvetica™ was designed by Max Miedinger (1910–1980).

List of effective files

20235103.xml a24
20235203.xml a21
20235303.xml a19
20236703.xml a57
20238503.xml a9
20238703.xml b8
20241103.xml a14
20243703.xml a14
20248703.xml a8
20248903.xml a10
20249003.xml a12
20249103.xml a4
20249203.xml a7
20250403.xml a21
20254903.xml a75a6
20255303.xml a12
20255603.xml a10
20257003.xml a40
20287303.xml a9
R0032.rcp a6
config.xml a5

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